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Report is a technical, economic and environmental evaluation of two small modular incinerator systems with heat recovery. One unit in North Little Rock, Arkansas has a thru-put of 100 tons of municipal solid waste per day and recovers steam. The other unit is a 25 TPD device located at the Rockwell Plant in Marysville, Ohio, and burns in plant waste to produce steam for heating and cooling the factory.

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SMALL MODULAR INCINERATOR SYSTEMS WITH HEAT RECOVERY

A Technical, Environmental, and Economic Evaluation

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U.S. ENVIRONMENTAL PROTECTION AGENCY
1979

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FOREWORD

This report is a technical, environmental, and economic evaluation of two small modular incineration-heat recovery facilities: one in the plant of the Truck Axle Division of Rockwell International Corporation in Marysville, Ohio, and the other in the Municipal North Shore Energy Plant in North Little Rock, Arkansas. The evaluation program was sponsored and directed by the Environmental Protection Agency (EPA) and the California State Solid Waste Management Board and was conducted under EPA Contract No. 68-01-3889 by Systems Technology Corporation (SYSTECH), Xenia, Ohio. The report was prepared by Richard Frounfelker, Staff Engineer of SYSTECH, for submittal to EPA.

The report explains the controlled air concept of the modern two-chamber incinerator, chronicles its development and application, and summarizes currently available systems for small-scale usage. Then the report details each of two facilities selected for the evaluation and presents the technical, environmental, and economic evaluation for each facility. In addition, the report projects the operating costs for the two facilities under optimum operating conditions and for municipal and industrial facilities in general.

Since the two evaluated facilities operate under different conditions with one burning municipal waste and the other industrial waste, they were not compared. Moreover, the reader is cautioned not to draw comparative conclusions.

ABSTRACT

This program involved a technical, environmental, and economic assessment of the feasibility of utilizing small modular incinerator systems for solid waste disposal in municipal and industrial applications. The assessment was implemented by (1) overviewing the state-of-the-art, (2) selecting two operational sites (one municipal and one industrial) representative of the state-of-the-art, and (3) subjecting these two sites to a rigorous field evaluation. The two facilities selected for this study were a municipal incinerator plant with a Consumat system in North Little Rock, Arkansas, and an industrial incinerator facility with a Kelley system in the plant of the Truck Axle Division of the Rockwell International Corporation in Marysville, Ohio. This selection was the result of a nationwide survey to find those two facilities which best satisfied several criteria. The principal selection requirements were a solid waste processing module with heat recovery and a capacity of 50 tons or less per day and its being representative of current technology, designs, and operational procedures.

Preparatory to the detailed description and evaluation of the two facilities, the report explains the controlled air concept of the two-chamber incinerator and briefly discribes its development and application. In addition, as a technical guide for the review and selection of currently available systems, the report details, according to available information, the 17 sources whose modular incinerators represent state-of-the-art technologies.

The technical evaluation presents the results of three weekly field tests at each site. The data was used to calculate the following for each system: the mass balance, the incinerator efficiency, the energy balance, the heat recovery efficiency, and the overall effectiveness of the system as a solid waste disposal facility.

The environmental evaluation presents the effects of the incinerator-heat recovery operation on the environment, specifically the atmosphere, the discharged process water, the landfills for refuse disposal, and the plant areas. An EPA Level One assessment presents a detailed analysis of the emissions.

The economic evaluation presents a detailed accounting of facility (1) capital costs, (2) operating and maintenance costs, (3) revenues, and (4) net operating costs.

Since the two systems differ in many respects and operate on dissimilar waste streams, they are not compared.

This report was submitted in fulfillment of Contract Number 68-01-3889 by Systems Technology Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1977 to March 1979.

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LIST OF SPECIAL ABBREVIATIONS

ABBREVIATIONS

ACFM -- actual cubic feet per minute
BOD -- biochemical oxygen demand
COD -- chemical oxygen demand
dB -- decibles re 20 $\mu N/m^2$
gr/DSCF -- grains per dry standard cubic foot
g/SCM -- grams per standard cubic meter
GJ -- giga joule (10^9 joules)
gpm -- gallons per minute
kℓ -- kilo liter (1000 liters)
ℓpm -- liter per minute
MBtu -- million British thermal units
MCF -- thousand cubic feet
MgPD -- megagrams per day
MJ -- mega joules
SCFM -- standard cubic feet per minute
ORP -- ortho-phosphate
TDS -- total dissolved solids
TOC -- total organic carbon
TPD -- tons per day
TS -- total solids
TSI -- Theta Sensors Incorporated

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SECTION 1

INTRODUCTION AND SUMMARY

PROGRAM OBJECTIVE, BACKGROUND, AND SCOPE

This study consisted of a technical, environmental, and economic evaluation of small modular incinerator systems with the overall objective being to determine the feasibility of their usage for solid waste disposal and heat recovery in municipal and industrial environments. The evaluation aspects of this report include (1) sufficient data and procedures to assess all technical, environmental, and economic aspects of small modular incineration-heat recovery systems; (2) a technical guide for the review and selection of currently available systems; (3) sufficient manufacturer and field test data to apply and/or adapt the current systems to particular needs; and (4) a data base for the future analysis and appraisal of advanced systems.

Recent technological advances and economic and environmental developments prompted the Office of Solid Waste Management of the Environmental Protection Agency to initiate this study. Some of the more significant advances are as follows: First, the incinerator manufacturers have successfully developed the two-chamber, controlled air incinerator for optimum efficiency and significantly reduced particulate emissions. Second, they have designed incinerators with integrated control systems to ensure their economic feasibility and efficient operation. Third, the small modular incinerator features simple and reliable operation, low maintenance costs, and payback frequently within 3 to 4 years (primarily in an industrial application).

Several economic and environmental factors have given added impetus to the attractiveness of the small modular incinerator with heat recovery. For example, municipalities are finding that such incinerators can address the problems (1) of rising landfill costs or rapidly diminishing landfill sites, (2) of complying with environmental pollution control regulations, and (3) of offsetting capital costs for waste disposal equipment through the revenues of recovered energy products and the savings of eliminated landfill expenses. Similarly, industries are seeing the advantages of burning waste rather than oil or gas (1) to recover the waste energy, (2) to save the expenditures for landfill disposal, (3) to meet the threats of fuel curtailments and rising costs, (4) to gain tax credits, and (5) to comply more readily with environmental control regulations. Furthermore, public opinion and government enactments lend strong encouragement and support to the widespread usage of the small modular incinerator with heat recovery because of its resource recovery and environmental control potential.

This report explains the controlled air concept of the modern two-chamber incinerator, chronicles its development and application, and summarizes currently available systems designed for small-scale usage. Then the report details each of two selected small-scale facilities and presents the technical, environmental, and economic evaluation of each, but in no way attempts to compare the two different systems. Finally, the 1978 economic data of the two evaluated facilities were adapted to estimate the operating costs at municipal and industrial facilities in general.

The two small incinerator facilities selected for intensive evaluation were a municipal incinerator plant in North Little Rock, Arkansas, and an industrial incinerator in the plant of the Truck Axle Division of the Rockwell International Corporation in Marysville, Ohio. In the selection of the two facilities, each had to meet three criteria: (1) a capacity designed for 50 tons or less of solid waste per day; (2) its integration with heat recovery equipment; and (3) its incorporation of the principles, designs, and operational procedures of current technology.

CURRENT MODULAR INCINERATOR TECHNOLOGY

Concept

The modular incinerators, generally consisting of a primary and a secondary combustion chamber, employ controlled air techniques to reduce the amount of air required for combustion in the primary chamber and to lower the level of their particulate emissions. These incinerators originated in the late 1960's, and their technologies and applications expanded in the 1970's.

The name "modular" was derived from the following: (1) each unit is identical, (2) each unit operates independently, and (3) one or more units can be readily integrated in an existing system as the waste demand increases. The terms "starved air," "substoichiometric," and "pyrolitic" denote the different combustion processes in the primary chamber. Sometimes these terms are used to denote the entire incinerator system.

Current Systems

A survey identified 16 manufacturers that produce incinerators capable of processing 454 to 1816 kg/hr (1000 to 4000 lb/hr) of industrial and/or municipal solid waste and of recovering the heat for energy production. The primary chambers in these incinerators operate under starved air (substoichiometric) or excess air combustion conditions. The incinerator systems can be grouped in five basic physical configurations. The larger systems have (1) automatic feeds consisting of loading hoppers, conveyors, and screws; (2) loading rams, moving grates, augers, and rotating chambers for continuous refuse flow through the primary chamber; and (3) heat recovery systems with fire or water tube boilers and other heat exchangers.

SUMMARY OF SELECTED SYSTEMS

Technical Capabilities

Performance--

At the North Little Rock municipal facility, where a Consumat incineration-heat recovery system is operative, the Consumat module proved capable of recovering 54 percent of the energy burned and of reducing the municipal solid waste 55 percent by weight and 95 percent by volume. Over the past 3 years, 13 Consumat incinerators have been burning municipal waste. Four of these incinerators are integrated with heat recovery equipment.

At the Marysville industrial facility, where a Kelley incineration-heat recovery system is operative, the Kelley module proved capable of recovering 54 percent of the energy burned and of reducing industrial refuse 95 percent by volume. Over the past four years, seven similar systems have been burning industrial waste. In addition, four units are burning municipal waste but without heat recovery.

The designs of both systems are still evolving. Each new facility introduces technological advances based on the experience gained from the previous installations. These technological improvements have advanced to the stage where the systems can burn waste and produce energy with satisfactory reliability.

Maintenance and Reliability--

The routine maintenance of both the Consumat and the Kelley systems consists principally of small refractory repairs and replacement of thermocouples and other switches, door seals, and motors. The maintenance requirements specific to each system are the weekly removal of soot from the boiler tubes in the Consumat system and the weekly cleaning of the induced draft fan blades and at least the semiannual cleaning of the boiler tubes in the Kelley system. The major maintenance requirement of both systems is the refractory replacement in 3 to 8 years, depending on the operational mode. In addition, because of its more extensive control system, the Consumat module requires more maintenance on the automatic control, hydraulic, and residue removal systems. In general, modules burning municipal waste require more maintenance than those burning industrial refuse. In addition, more operational interruptions must be anticipated when burning municipal waste because of the jams caused by large metal objects in the waste and the greater frequency of the above-mentioned routine maintenance. Moreover, the slag formed from the fusion of glass and metals frequently plugs air injection ports and degrades the refractory.

Operation--

The Consumat system with its 100-TPD capacity at the North Little Rock facility required nine personnel: one supervisor, one clerk, one truck driver, and two operators for each of three shifts. The Kelley system at the Marysville facility with its capacity of 12 TPD and limited operational usage of two shifts, 5 days per week, required only one full-time operator per shift. As additional part-time assistance was required, it was usually supplied by the plant maintenance staff. Neither facility required waste preprocessing, although operators at both facilities removed such materials as pipe and wire before refuse loading and hand-loaded some materials into the incinerator hopper to prevent jamming.

The Consumat system includes (1) a remotely controlled display panel to instruct the loading operator on how large a load to collect and when to deposit it into the incinerator hopper, (2) an automatically modulated air control to maintain a desired temperature in each of the two combustion chambers, and (3) an automatic ash removal system. The Kelley system allows the operator to judge the size and frequency of each refuse loading. With the airflow preset to handle a specific waste stream, only a high temperature lockout on the Kelley system prevents extreme refuse overloading. In both systems, overfeeding causes high temperatures in the secondary chamber, excessive gaseous emissions, and wasted energy. On the other hand, underfeeding reduces the system throughput rate and the resultant low chamber temperatures may require burning auxiliary fuel. Therefore, proper feeding of the incinerators to ensure proper combustion is essential for optimum incinerator performance.

Environmental Acceptability

Emissions Compliance--

Neither facility had a high enough daily refuse consumption, i.e., over 50 tons per day per module or 250 tons per day per facility, to be considered under the Federal standard of performance for new stationary sources or the prevention of significant deterioration regulations. Therefore, a new source review was not required during the preconstruction planning. Both plants complied with their respective state-imposed emissions standards and building permits. If either facility had more than a daily 250-ton throughput, it would have been subject to a new source review and would have required the best available emissions control such as an electrostatic precipitator or a fabric filter.

At both facilities, the gaseous emissions related directly to the size of the load fed into the incinerator. The sulfur and nitrogen oxide levels in the stack emissions were negligible. At the North Little Rock facility, the chloride emissions varied from 100 to 600 mg/m^3. No direct relationship was evidenced between the loading or sizing of the particulate emissions and the modulating air supply.

EPA Level 1 Analysis--

At both facilities, 90 percent of the stack particulates were less than 7 micrometers in diameter; the stack emissions had a wide range of metals and halogens in minute amounts; and the residue had a high pH and contained traces of many metals such as zinc, tin, lead, and cadmium.

Economic Effectiveness

Capital Cost--

For an incinerator with heat recovery, the capital cost of refuse processed daily was computed at $15,000 per ton (based on 1977 dollars).

The relationship between the capital cost per ton and the incinerator capacity was found to be nearly linear up to a 200-TPD capacity. A 12-TPD industrial system would cost $220,000 to $300,000, while a 100-TPD municipal system with a 300-meter steam/condensate return line would cost about $1,500,000 (based on 1977 dollars).

Operational Cost--

On the basis of the test data, the optimum annual operating cost (based on 1978 dollars) of a 100-TPD municipal facility would be $370,000. With optimum steam revenues and tipping fees of $305,000, the net annual operating cost of this facility would be $65,000 or $3.01/Mg ($2.72/ton) of refuse processed. For a 12-TPD industrial facility, the optimum annual operating cost (based on 1978 dollars) would be $117,944. Applying credits for disposal savings and energy savings of $82,620 and $139,594, respectively, results in a net savings of $104,270 or $31.94/Mg ($28.96/ton) of refuse processed. The facility finances are highly sensitive to the refuse processing rate, the operating time, and the steam sales price.

SECTION 2

THE SMALL MODULAR INCINERATOR

CONTROLLED AIR INCINERATION

Introduction

During the 1960's virtually all operational incinerators were still uncontrolled air units. To ensure a high degree of combustion in these incinerators, air was supplied in fixed amounts with a volume considerably more than that required for stoichiometric combustion. The conventional grate incinerators also required large volumes of underfire air to cool the refuse bed and thereby to prevent grate burnout. In turn, the high velocities and large volumes of air required large blowers with high horsepower motors. Consequently, large quantities of both combustible and inert particulates were discharged to atmosphere with the exiting flue gases.

The late 1960's introduced the controlled air incinerator, that is, an incinerator with an afterburner or an incinerator with a primary and a secondary combustion chamber. The term "controlled air" denotes the control and regulation of the air flowing into the two combustion chambers. Whereas the air supplied to the previous incinerators was uncontrolled, the velocity and volume of the air supplied to the new units are kept at a calculated minimum to improve the efficiency of the combustion process, to lower the horsepower of the fan motors, and to reduce the amount of the particulates entrained in the exiting flue gases. The airflow can be either preset to a calculated level based on the amount and type of the waste burned or continuously modulated to produce the optimum combustion with the varying system needs and chamber conditions.

The first, or primary, chamber is also called the lower chamber or the combustion chamber. Similarly, the second, or secondary, chamber is also called the upper chamber, the ignition chamber, the afterburner, or the thermal reactor.

Some of the controlled air incinerators are called starved air incinerators because of the substoichiometric combustion in the primary chamber. The term "pyrolytic" is also applied to the starved air incinerator, but such a description is not correct. The process of partial oxidation of the waste in the primary chamber is sometimes referred to as pyrolysis. However, pyrolytic combustion chambers use higher temperatures and a lower amount of substoichiometric combustion air than the starved air incinerators.

The term "modular" as a descriptor for the controlled air incinerator developed as follows: The controlled air incinerators designed for burning commercial and industrial waste have been constructed of integral components, one for the primary chamber, one for the secondary chamber, and so on. Each component has been assembled and packaged in the factory for immediate on-site installation. Only electrical, fuel, water, and gas duct connections are required at the installation site. When the waste volume has exceeded the capacity of the installed units, additional incinerators are incorporated to meet the increased demand. Since the additional incinerators are constructed and function as modules, the integrated units became known as modular incinerators. While the capacity of the modular incinerators has increased from one to four tons of waste per hour, most of the components are still completely assembled and packaged in the factory for immediate on-site installation.

Controlled air incinerators are grouped under two main categories according to the degree of combustion, complete or partial, in the primary chamber. Since the complete combustion requires excess air and the partial combustion needs substoichiometric conditions, the categories are excess air incinerators and substoichiometric incinerators. While the airflow in the excess air incinerators is limited, it is sufficient for excess stoichiometric combustion in both chambers (see Figure 1). In the substoichiometric incinerators, the air introduced into the primary chamber ranges from 30 to 40 percent of the amount required for stoichiometric combustion, and the air fed to the secondary chamber ranges from 100 to 150 percent of the excess air needed to achieve complete combustion (see Figure 1).

In addition to the airflow regulation, the combustion process is controlled by varying the waste feed rate and, in some incinerators, by spraying water into the primary chamber.

Feeding Mechanism

The waste to be burned is fed into the primary chamber in controlled batches and at prescribed intervals. The batch size, usually between one and four cubic yards, varies with the waste characteristics, particularly particle size, bulk density, and Btu content, as well as with the incinerator capacity. Except for the removal of white goods and large metals, the waste stream usually need not be preprocessed before it enters the primary chamber.

The appropriate type of feeding mechanism for a particular installation depends on the waste characteristics. Most incinerators burning bulk and heterogeneous waste have a hopper to receive the waste and a hydraulically driven ram to push the waste from the hopper into the primary chamber. For other types of waste, the feeding mechanisms include air lock hoppers, screw augers, and liquid and pneumatic systems.

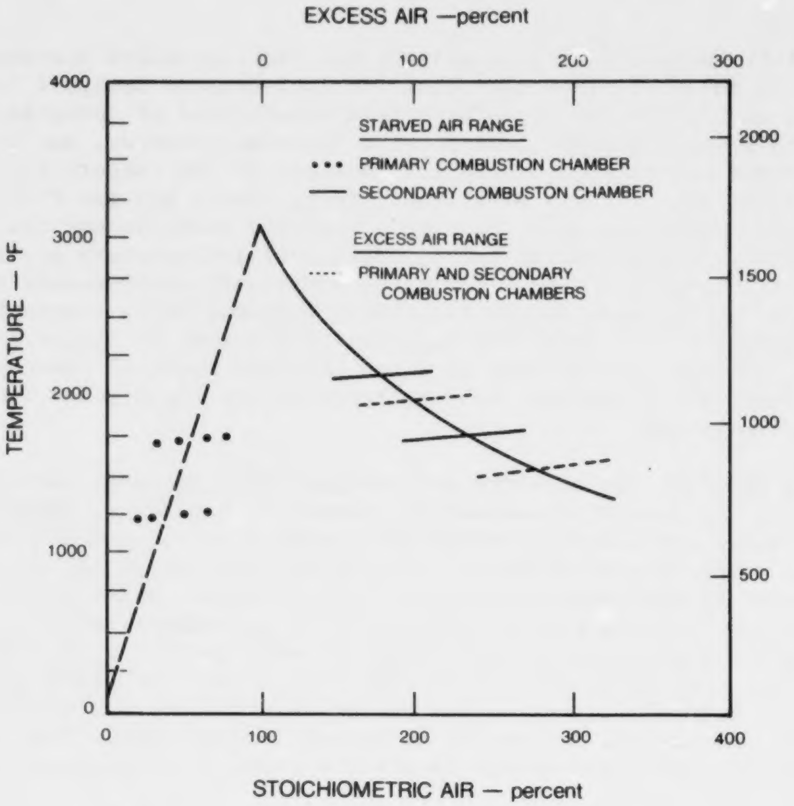


Figure 1. Operational ranges (stoichiometric air percentage and temperature) for controlled air incinerators.

Primary Chamber

During start-up of the substoichiometric incinerator, one or two auxiliary burners in the primary chamber progressively dry, volatize, and ignite the waste. When the combustion reactions start, the volatile gases and carbons are released with most of the fixed carbons remaining in the chars on the hearth. When the combustion rate is sufficient to sustain partial oxidation reactions, the auxiliary burners are shut off. The partial oxidation is maintained by supplying the primary chamber with less air than that needed for the complete combustion of the gases and chars. The combustible gases and particulates generated in the primary chamber flow into the secondary chamber where they are combusted almost completely. If the retention time in the primary chamber is long enough and air is introduced from underneath the hearth, most of the fixed carbon in the chars is also combusted. Any unburned carbon is removed with the ash and other inert materials.

During start-up of the excess air incinerator, an auxiliary burner in the primary chamber dries, volatizes, and ignites the waste. With excess air introduced under, over, and beside the waste, the combustion is sustained sufficiently to turn off the burner and to burn both the gas by-products and the combustible solids of the initial and subsequent waste batches. As the gases flow into and through the secondary chamber, any remaining combustibles are burned completely.

Secondary Chamber

In the substoichiometric incinerator, the secondary chamber is initially heated by an auxiliary burner. When the partially oxidized combustibles flow from the primary chamber into the secondary chamber, the burner ignites them. Then as the burning gases mix with additional air, the heat increases to temperatures between 760° and 871° C (1400° and 1600° F) for complete combustion. As the combustion generating this heat is self-sustaining, the burner is shut off.

In the excess air incinerator, no auxiliary burner is needed in the secondary chamber since the temperature of the entering gases is high enough to sustain combustion as more air is added. The excess air introduced into both chambers ranges from 75 to 150 percent of the air needed for combustion. The excess air supplied to the secondary chamber is injected tangentially to produce turbulence which thoroughly mixes the air with the combustible gases and particulates. Baffles in the secondary chamber and over-and-under partitions between the chambers are installed to promote the turbulence. The excess air, the turbulence, and the retention time collectively provide the conditions for the nearly complete burning of all combustible gases and particulates.

Temperature Control

The temperature in the primary chamber is sensed by thermocouples with set temperature points and maintained at a set point with a 37.7° C (100° F) control band by varying the waste feed rate and the amount of air injected and by spraying the chamber with a water mist. While the set points vary with the incinerator manufacturer and the waste to be burned, they generally range from 694° to 982° C (1200° to 1800° F).

The temperature in the secondary chamber is also sensed by thermocouples with set points. When the chamber temperature reaches the set points, the thermocouples activate controllers which modulate airflow dampers and turn the burner on and off. More air fed into the secondary chamber reduces the temperature while less air increases the temperature. On the other hand, more air fed into the primary chamber produces more volatile gas. The combustion of the gas in the secondary chamber results in increased temperatures.

In the substoichiometric incinerators, the thermocouple set points for low temperatures range from 694° to 871° C (1200° to 1600° F) and those for high temperatures range from 982° to 1093° C (1800° to 2000° F). When the chamber temperature falls below the low temperature setting, the auxiliary burner is reignited. When it exceeds the high temperature setting, the waste loading system is locked out to prevent feeding more waste into the primary chamber. Also, in some incinerators a water spray is activated to suppress the combustion reaction.

Residue Removal

Ash and other incombustible residue which settle on the hearth of the primary chamber after the combustion process are periodically removed by manually or automatically operated systems. In the manual system, the operator scoops out the ash (by shovel or front-end loader) after the unit has been shut off and cooled down. In the automatic system, the ash is pushed or forced ahead of the burning waste until it exits the chamber, generally through a drop chute into a water-sealed pit or an air lock chamber. The automatic systems include the loading ram which pushes the residue out as well as the raw waste in during the loading cycle; the chamber-incorporated rams which push the residue out between loading cycles; and other internal devices such as moving grates, conveyors, augers, and rotating kilns which continuously force the ash through the primary chamber.

Energy Recovery

Several incinerator systems incorporate water or fire tube boilers to recover the thermal energy from the flue gases exiting the secondary chamber. The temperatures of these gases are generally between 871° and 982° C (1600° and 1800° F). Either an induced draft fan or an aspiration fan draws the flue gas through the boiler. Both fan types are downstream of the boiler. While the induced draft fan is in the gas stream, the aspirator is outside the gas stream. The latter fan injects fresh air through an aspirator section of the exhaust stack where it produces a negative pressure within the boiler such that the flue gas is drawn into and through the boiler without reaching the fan. Since the induced draft fan is in the gas stream, it is subjected to the damaging effects of high temperatures and to the abrasive and corrosive effects of the particulates and vapors within the flue gases.

Waste Consumption

The waste consumption capacity of the controlled air incinerators varies greatly with the waste characteristics. The energy content is the most important factor in determining the capacity. The modular units are designed to burn a specific amount of energy per hour; therefore, the higher the energy content per unit mass, the slower the feed rate. The incinerator capacities in industrial plants and those in municipal plants are conventionally expressed in waste feed rates of kilograms (pounds) per hour and megagrams (tons) per day, respectively.

Since industrial plants usually have a small volume of fairly homogeneous waste with a high energy content per unit mass, the waste is fed at a slower rate. The capacity of the smallest incinerators is about 136 kg/hr (300 lb/hr) while that of the largest incinerators is up to 1335 kg/hr (2500 lb/hr). Manufacturers indicate that the 227 to 318 kg/hr (500 to 700 lb/hr) range is the smallest incinerator capacity that would make heat recovery systems economical. On the other hand, since municipal plants generally have a large volume of heterogeneous waste with a low energy content per unit mass, the waste can be fed at a faster rate. The capacities of the substoichiometric incinerators range from 10.9 to 45.5 Mg/day (12 to 50 TPD) while those of the excess air incinerators range from 10.9 to 272.1 Mg/day (12 to 300 TPD).

Stack Emissions

Although the controlled air combustion in the two chambers burns virtually all the combustible gases and particulates, the stack emissions contain some unburned carbon, as well as inert particles and vapors, entrained in the flue gas stream.

If the waste is homogeneous and has a high carbon content and few small inert particles, the combustion can be controlled sufficiently to discharge the flue gas with emissions at acceptable levels. Consequently, industrial incinerators up to 50 TPD capacity can generally be designed and operated so that their stacks do not require emission control equipment. In contrast, since the waste in municipal incinerators has a high inert particle content as well as a heterogeneous make-up and a low carbon content, it is difficult to maintain a steady-state combustion and consequently to keep the emissions at acceptable levels. Therefore, stack emission control equipment is normally incorporated in the larger controlled air incinerators burning municipal waste. Since the modular units with a capacity of 50 TPD or less are not subject to the Federal particulate emission standard of 0.08 gr/DSCF, only the applicable state regulations on emission standards apply. When the facility capacity is over 50 TPD, the new Federal stationary source emission regulations under the Clear Air Act apply. The regulations can be found in the Federal Register Volume 43 - No. 118, June 19, 1978.

HISTORY OF CONTROLLED AIR INCINERATION

Introduction

During the period from 1960 to 1970, incineration was a recognized economical method of solid waste disposal. A reported 265 to 299 incineration plants were in operation across the United States.

The Incinerator Institute of America (IIA), an association of 30 to 35 excess air incinerator manufacturers, was considered the authority on incineration. Consequently, virtually every city in the United States adopted the IIA specifications as part of its building code. Therefore, whenever an incinerator built to the IIA specifications smoked, the environmental control official blamed the violation on its operation since the incinerator construction would have complied with the building code. On the other hand, the city codes restricted the amendment of the IIA specifications to allow new incinerator developments.

The enactment of the Clean Air Act in 1970 began the closure of the incineration facilities because of the reluctance on the part of the facility owners to add air pollution control equipment to meet the more stringent air emissions standards. During the next 4 years, an estimated 105 to 135 of the facilities had been closed. In May 1978 a survey by the Operations Committee, Solid Waste Processing Division, and the American Society of Mechanical Engineers (ASME) revealed that of the 106 plants responding, 52 had been closed down. Closure was again due to failure to meet air pollution standards. The excessive cost of installing air emission control devices has led most of the cities to seek a more economical method of solid waste disposal.

As the incineration facilities closed because of the Clean Air Act, many of the IIA companies also folded. As the uncontrolled (excess) air incinerator industry diminished, the controlled air incinerator business correspondingly increased.

Many of the smaller modular incinerators were first developed by manufacturers of the larger uncontrolled air incinerators.

In the late 1950's Gordon Hoskinson, known as the father of modern incineration, developed the controlled air incinerator, a smokeless unit based on the principle of afterburning. Yet the new type of incinerator did not materialize until 1964 when Hoskinson and George Flowers left Smokatrol to patent the modified Hoskinson design with a two-phase afterburner. Then they started Waste Combustion, now called Consumat Systems, in Richmond, Virginia.

In the late 1960's Midland Ross and Combustion Engineering entered the controlled air incinerator industry by adapting the Smokatrol design to manufacture the Radicator and Combustall, respectively. While Midland Ross contracted with Environmental Control Products in the early 1970's to manufacture the Radicator, both companies withdrew from incinerator manufacture by 1975.

With its first controlled air incinerator manufactured in 1965, Consumat Systems produced a prototype unit for municipal installation in 1969. This unit was a single, noncontinuous-operation module that could process 11.3 Mg/day (12.5 TPD) of waste.

Formerly associated with Consumat Systems, Gene White founded Comtro in 1968 to market his variation of the Hoskinson design with a secondary afterburner instead of a stack burner.

Upon joining Kelley in 1970, Hoskinson developed an incinerator similar to the Smokatrol unit.

Econo-Therm entered the incinerator industry when it bought out Heston which had previously bought out Joseph Goder, the largest of the old IIA companies.

In 1969 John Basic started as a Consumat Systems dealer. As he received the company's incinerators, he customized them to suit particular applications. He later formed Basic Environmental Engineering to design and manufacture his own incinerators.

Plibrico manufactured starved air incinerators for 2 years. After the company stopped its production, Simonds, a Plibrico distributor, improved the design and continued the manufacture.

In 1973 Consumat Systems had its first waste-to-energy system installed in a hospital. Also in the same year, the company built its first continuous-operation unit. In 1975 the company's first municipal system with energy recovery was installed.

Design Evolution

The first-generation models of the controlled air modular incinerator were small refractory-brick-lined chambers with a vertical afterburner chamber and stack combination. Capacities were in the range of 45.4 to 318 kg/hr (100 to 700 lb/hr) of commercial or industrial waste. The controls on these incinerators were minimal, i.e., on/off switches for the burner and preset air blowers. The primary uses for the incinerators were to burn waste generated from hospitals, stores, and restaurants.

Subsequently, the afterburner stack was replaced by a secondary chamber, and the capacity of the units was increased up to 1135 kg/hr (2,500 lb/hr). The control of temperature and airflow in the secondary chamber allowed the burner to be modulated or even shut off after a temperature high enough for self-sustaining combustion of the gases was reached. This minimized the consumption of auxiliary fuel.

The earlier units were loaded through a door before the unit was ignited. Because of the positive pressure in the chamber and the presence of pyrolysis gases, opening the door while the waste was burning resulted in flames leaping out the door. Double doors and temperature lockouts were developed to prevent the operator from being injured by these flames. Later, a slight negative pressure was induced in some models to prevent flame escape as the doors were opened. On the larger units, the loading system advanced from the door loaders to an enclosed hopper and ram module. The latter equipment allowed more waste to be quickly and safely loaded into the primary chamber. Pneumatic feeds for small-particle waste and pump feeds for liquid waste were also developed.

Ash in the primary chamber was originally removed manually after the chamber had cooled sufficiently. While automatic, continuously operating residue removal systems have been developed for the larger incinerators, most of the smaller incinerators (those with capacities less than 318 kg/hr [700 lb/hr]) still have the ash removed manually.

Although the larger modular incinerators were integrated with heat recovery systems, their high cost initially made their sale difficult. However, when oil and gas costs rose with the recent energy crisis, the waste incinerator with heat recovery became an economical alternative to landfills and conventional fuels. Incorporating the heat recovery systems with the incinerator necessitated the addition of expanded control systems.

CURRENT SMALL MODULAR INCINERATOR SYSTEMS

This section briefly describes the principal small modular incinerator systems currently available. Table 1 compares their major characteristics. The data in this table and the following information on the 17 sources were obtained from sales literature of the manufacturers and from conversations with the manufacturer representatives. Table 2 lists the addresses and telephone numbers of the 17 sources.

There are many more manufacturers of modular incinerators than those listed here. Those that are discussed represent the different design approaches and most have several incinerator and energy recovery units in operation with capacities ranging from 10.9 to 90.7 Mg/day (12 to 100 TPD).

Within the constraints of the available information, the following paragraphs describe the small modular incinerator systems of the 17 sources in the alphabetical order of the source name. After the individual (source) descriptions, the systems, along with the corresponding sources and representative illustrations (see Figures 2 through 9 on pages 27 through 31), are grouped under five physical categories.

Basic Environmental Engineering, Inc.

The Basic incinerators are designed to burn industrial and municipal waste. Capacities of these units range from 32.6 to 136.0 Mg/day (36 to 150 TPD). Information on units in operation is as follows: one 20,000,000 Btu/hr unit operating since 1972; one 8,000,000 Btu/hr and two 16,000,000 Btu/hr units operating since 1973; one 28,000,000 Btu/hr unit operating since 1975; and one 48,000,000 Btu/hr unit operating since mid 1979.

This incinerator has three excess air combustion chambers. A rack- and pinion-driven ram feeder pushes the waste into the rectangular-shaped horizontal primary chamber. The water wall construction of this chamber provides additional heat recovery. The chamber is kept at 982° C (1800° F) to maintain stoichiometric conditions and is operated at a slight negative pressure to prevent leakage of emissions. Modulated combustion air forced through numerous high static, low velocity, and low volume jets on the front of the chamber produce a laminar airflow through the ash bed. The primary chamber has two burners which are used for start-up firing and supplemental heat during operational firing. At the lower part of the chamber, the two sides slope toward the middle where bomb bay doors form the chamber bottom. These doors are opened for batch ash removal. The ash is removed continuously through a vertical ash chute at the end of the chamber. A horizontal ram at the bottom of the chute pushes the ash through an airlock into a container. Basic now has a moving hearth floor to move the burning refuse through the main chamber and drop it into a water seal pit with automatic ash removal from the pit.

TABLE 1. MANUFACTURERS OF MODULAR INCINERATORS

Manufacturer	Incinerator type municipal no. with heat recovery		Incinerator type industrial no. with heat recovery		Air emissions control equipment normally employed	Combustion process	Capacity range Mg/day (TPD)
	with heat recovery	without heat recovery	with heat recovery	without heat recovery			
Basic	0	0	6	6		#	33 (36) to 136 (150)
Burn-Zol	0	0	1	0	X	+	up to 22 (24)
C.E. Bartlett	0	0	0	19	X	#	up to 35 (38)
Clear Air	0	3	0	0	X	#	44 (48) to 272 (300)
Comtro	0	3	3	N		+	up to 22 (24)
Consumat	4	13	4	N	X	+	up to 45 (50)
Econotherm	0	0	4	N		+	up to 29 (32)
ECP	1	0	14	N		+	up to 43 (48)
Giery	1	0	0	0	X	#	22 (24) to 65 (72)
Kelley	0	6	49	N		+	up to 22 (24)
Lamb-Cargate	0	0	2	0		+	up to 181 (200)
Morse-Boulger	0	4	1	0	X	#	up to 227 (250)
SEE	0	1	0	0	X	+	up to 136 (150)
Simonds	0	0	7	N		#	up to 27 (30)
Smokatrol	0	0	1	N		+	up to 37 (30)
Washburn	1	1	0	0	X	+	up to 22 (24)

# Excess air incineration.

+ Starved air incineration.

N Numerous.

In the original incinerator, the secondary and tertiary chambers were rectangular-shaped horizontal vessels equipped with a burner and modulating air blowers. The chambers were maintained at 982° C (1800° F) with excess air conditions. Presently the secondary and tertiary chambers are double-wall, cylindrical chambers. All the excess air is heated from the inner wall heat losses and acts as a heat recuperator.

The incinerator system can be integrated with gas-to-air, steam, and hot water heat recovery systems such as those supplied by Delta, IBW, and Johnson with both fire and water tube boilers.

TABLE 2. ADDRESSES AND TELEPHONE NUMBERS OF MODULAR INCINERATOR MANUFACTURERS

Basic Environmental Engineering, Inc.
21W161 Hill
Glen Ellyn, Illinois 60137
(312) 469-5340

Burn-Zol
P.O. Box 109
Dover, New Jersey 07801
(201) 361-5900

C. E. Bartlett-Snow
200 West Monroe
Chicago, Illinois 60606
(312) 236-4044

Clear Air, Inc.
P.O. Box 111
Ogden, Utah 84402
(801) 399-9828

Comtro Division
180 Mercer Street
Meadville, Pennsylvania 16335
(814) 724-1456

Consumat
P.O. Box 9574
Richmond, Virginia 23228
(804) 746-4120

Econo-Therm
1132 K-Tel Drive
Minnetonka, Minnesota 55343
(612) 938-3100

Environmental Control Products
P.O. Box 15753
Charlotte, North Carolina 28210
(704) 588-1620

Environmental Services Corporation
P.O. Box 765
Crossville, Tennessee 38555
(615) 484-7673

Giery Company, Inc.
P.O. Box 17335
Milwaukee, Wisconsin 53217
(414) 351-0740

Kelley Company, Inc.
6720 N. Teutonia Avenue
Milwaukee, Wisconsin 53209
(414) 352-1000

Lamb-Cargate
P.O. Box 440
1135 Queens Avenue
New Westminster, British Columbia
V3L 4Y7 (604) 521-8821

Morse-Boulger
53-09 97th Place
Corona, New York 11368
(212) 699-5000

Scientific Energy Engineering, Inc.
1103 Blackstone Building
Jacksonville, Florida 32202
(904) 632-2102

Simonds Company
P.O. Drawer 32
Winter Haven, Florida 33880
(813) 293-2171

U.S. Smelting Furnace Company
(Smokatrol)
P.O. Box 217
Belleville, Illinois 62222
(618) 233-0129

Washburn and Granger
85 5th Avenue
Patterson, New Jersey
(201) 274-2522

Burn-Zol

The Burn-Zol units are designed to burn solid and liquid industrial wastes and hospital pathological wastes. The units can be designed to burn from 454 to 1816 kg/hr (1,000 to 4,000 lb/hr) of waste. Recent industrial installations are located at Connelly GPM, Elizabeth, New Jersey; Allied Chemical, Metropolis, Illinois; and Alcolac Corporation, Sedalin, Missouri. The Alcolac facility has a hot water waste heat recovery system used in conjunction with a gas-to-air heat exchanger to achieve hot air recovery.

The primary chamber in each of these incinerators is a substoichiometric combustion unit. For each application, the manufacturer custom-designs the refuse feeder. The primary chamber is a cylindrical vertical vessel whose outer shell is air-cooled or insulated to a 52° C (125° F) maximum skin temperature. This chamber has a modulating burner with a 20:1 turndown ratio for better fuel economy. Substoichiometric conditions prevail when the chamber is kept at 694° C (1200° F). The manufacturer also custom-designs the ash removal equipment for each application. The vertical secondary chamber is operated at 100 percent excess air and maintained at 760° C (1400° F) by an afterburner. Unique to this system, all metal components are made of 400 series stainless steel. Heat recovery equipment, which can be integrated with the incinerator, is available for low pressure steam and hot water.

C. E. Bartlett Snow

The incinerator, called the C. E. Raymond Tumble Burner^{TM}, is designed to handle industrial waste. Capacities range from 45.4 kg/hr (100 lb/hr) to 1362 kg/hr (3,000 lb/hr). There are 19 units in operation. Some of the largest units are in the following plants: Rollins-Purle, Bridgeport, New Jersey, burning chemical sludges and plastics; Eli Lilly, Clinton, Indiana, burning wood, cardboard, and mixed waste; Amoco Chemicals, Decatur, Alabama, burning chemical residue; Mill Creek Treatment Plant, Cincinnati, Ohio, burning municipal sewerage sludge; and Richardson-Merrill, Swiftwater, Pennsylvania, burning egg waste. The Tumble Burner is an excess air incinerator. An auto-cycle ram feeding system pushes the waste into a rotary kiln primary chamber. A blower supplies the kiln with 140 percent excess air. A burner at the discharge end provides the kiln with supplemental heat. The fuel flow to the burner is modulated to maintain the kiln between 760° and 871° C (1400° and 1600° F) or higher for toxic materials. The ash is discharged in batches through a knife gate or bomb bay doors.

The secondary chamber has a burner and an auxiliary air source. The fuel flow to the burner is varied to keep the chamber between 871° and 982° C (1600° and 1800° F).

Since the system is not usually integrated with heat recovery equipment, a precooler chamber is installed after the secondary chamber. In addition, a scrubber is installed after the precooler so that the exhaust gases will meet the air pollution standards. Finally, an induced draft fan and a stack are installed after the scrubber to maintain a slight negative pressure in the system and to draw the flue gases through the system. The system may incorporate heat recovery equipment if desired.

Clear Air

Both of the chambers in this incinerator are excess air combustion units. An apron conveyor projecting into the primary chamber feeds the waste into the incinerator system. A radiation screen wall hanging from the system ceiling protects the conveyor. The combustion units in this system are designed to burn municipal solid waste. Capacities of the modules range from 1.8 to 13.3 Mg/hr (2 to 12.5 TPH). Installations in full operation are located at Weber County, Utah, and Hamilton, Montana, with capacities of 408.2 Mg/day (450 TPD) and 15.4 Mg/day (17 TPD), respectively. A 68.0 Mg/day (75 TPD) unit in Martinsville, Indiana, is in operation only one day per week. No heat recovery is provided at the sites.

The entire combustion system is contained in a horizontal rectangular vessel with baffle walls separating the various chambers. The primary chamber is maintained at 1010° C (1850° F) and stoichiometric conditions. Patented reciprocating grates move the refuse through the primary chamber and discharge the ash into a water quench tank. With the tank providing an air seal, a drag conveyor removes the discharged ash. The temperature in the primary chamber controls the feed rate and the amount of underfire air.

The secondary chamber is operated at the same conditions as the primary chamber, i.e., 150 percent excess air and a temperature of 982° C (1800° F). There are no burners in either combustion chamber.

The incinerator system is integrated with heat recovery equipment. Upon leaving the secondary combustion chamber, the gases pass through a waste heat watertube boiler with the tubes arranged vertically. The emissions are controlled by passing the gases through an electrostatic precipitator.

Comtro

The Comtro incinerator, with the primary chamber being a substoichiometric combustion unit, was designed to burn industrial, commercial, and municipal wastes. The capacity of the modules range from 45.4 to 1362 kg/hr (100 to 3,000 lb/hr). Installations that are burning 10.9 to 13.6 Mg/day (12 to 15 TPD) per unit of municipal waste without heat recovery are located in Pelham, New Hampshire; Prudhoe Bay, Alaska; Caracas, Venezuela; and Riyadh City, Saudi Arabia. A new facility has recently been constructed at Jacksonville, Florida, for the U.S. Navy. The facility processes the Navy base municipal waste and then burns it in four units each with a capacity of 908 kg/hr (2000 lb/hr). Industrial installations with capacities of 545 to 908 kg/hr (1200 to 2000 lb/hr) with heat recovery systems are located at Moore Business Forms, Honesdale, Pennsylvania; Milprint, Downington, Pennsylvania; Knoll International, East Greenville, Pennsylvania; Waste Research, Eau Claire, Wisconsin; Thomp Linen, Fargo, North Dakota; and Douglas Furniture, Chicago, Illinois.

The primary chamber in this incinerator is a substoichiometric combustion unit. As an automatic hydraulic ram feeds waste into a horizontal cylindrical primary chamber, it forces previous waste deposits through the chamber. The ash is removed by either a dry or a wet system. The normal operating temperature for the primary chamber is between 982° and 1093° C (1800° and 2000° F). Supplementary heat is supplied when the temperature drops below 871° C (1600° F), and excess air and a water spray are introduced when the temperature approaches 1093° C (2000° F). With an internal construction to promote combustion and a controlled airflow to regulate temperature, the horizontal secondary chamber normally operates at 982° C (1800° F). Combustion air to both chambers is supplied through underfire ports.

The incinerator system can be integrated with a firetube boiler for heat recovery. When the boiler is installed, an induced draft fan above the boiler draws the hot gases across the incinerator stack, through the boiler, and then back to the incinerator stack for discharge to atmosphere.

Consumat

The Consumat incinerators are designed to burn industrial, commercial, and municipal solid waste. Capacities of single modules range from 227 to 908 kg/hr (500 to 2000 lb/hr). Municipal installations are located in Blytheville, Arkansas, 63.5 Mg/day (70 TPD) with steam generation; Siloan Springs, Arkansas, 18.1 Mg/day (20 TPD) with steam generation; North Little Rock, Arkansas, 90.7 Mg/day (100 TPD) with steam generation; and Salem, Virginia, 90.7 Mg/day (100 TPD) with steam generation. Industrial sites with steam generation are the Pentagon, Washington, D.C., and John Deere, Dubuque, Iowa, each burning 908 kg/hr (2000 lb/hr).

The primary chamber in each of these incinerator systems is a substoichiometric combustion unit. A multiple hydraulic ram and terraced hearth system pushes the waste into and through the primary combustion chamber. This chamber is operated at approximately 694° C (1200° F) to maintain substoichiometric conditions. A ram discharges the residue into a water quench seal tank where a drag conveyor removes the residue for subsequent disposal. The temperature in the secondary chamber is kept between 982° and 1010° C (1800° and 1850° F) by modulating the air into the primary and secondary chambers. An auxiliary burner in the secondary chamber is automatically activated when the temperature in this chamber falls below 927° C (1700° F).

For heat recovery, the incinerator system is integrated with a watertube waste heat boiler and a soot blowing system. When the boiler is operating, airflow produced by an aspirator fan draws the hot gases through the boiler and then to a separate boiler stack.

A schematic layout of the system is shown in Section 4.

Econo-Therm

Econo-Therm specializes in custom-designed incinerators including small modular systems to burn industrial, hospital, and commercial wastes.

Capacities of the units range from 45.4 to 1335 kg/hr (100 to 2500 lb/hr). Installations with heat recovery are located in Panoply Corporation, Lexington, Tennessee; Midwest City Hospital, Midwest City, Oklahoma; and Rincon High School, Tucson, Arizona.

In the larger basic design, a ram feeder pushes the waste into and through the substoichiometric primary combustion chamber, with the residue being removed by a custom-designed ash removal system. Unique to the Econo-Therm modular incinerator systems is the large two-pass secondary chamber. A single fan supplies combustion air to both the primary and the secondary chamber. Air is introduced into the secondary chamber through a series of holes.

The small modular system can be integrated with a firetube waste heat boiler for heat recovery. When the boiler is installed, an induced draft fan draws the hot gases through the boiler and then discharges them to atmosphere through a boiler stack.

Environmental Control Products

Environmental Control Products designs and builds incinerators to burn industrial, commercial, and municipal waste. The units have a capacity range of 45.4 to 1816 kg/hr (100 to 4000 lb/hr). Industrial installations with waste heat recovery are at Nationwide Tire Co., Wilkes-Barre, Pennsylvania; Groveton Papers Co., Groveton, New Hampshire; Pen Dairies, Lancaster, Pennsylvania; Funk Seeds International, Bloomington, Illinois; West Co., Mellville, New Jersey; Trane Company, Clarksville, Tennessee; and Pratt and Whitney, East Hartford, Connecticut. The Groveton, New Hampshire, facility burns municipal waste one day per week.

The primary chamber in each of these incinerators is a substoichiometric combustion unit. A hydraulic ram feeder pushes the waste into and through a horizontal cylindrical primary chamber. This chamber is operated at 40 percent theoretical air and at temperatures between 815° and 982° C (1500° and 1800° F). The variation of the waste feed and the modulation of the underfire air controls the temperature of the primary chamber. Action of the loading ram pushes the ash through a hole at the end of the chamber where a wet module system with a drag chain conveyor removes the ash. A dry module ash removal system is available as an option.

The secondary chamber is a horizontal cylindrical vessel mounted above the primary chamber. Auxiliary burners in this chamber are modulated to maintain chamber temperatures between 871° and 1204° C (1600° and 2200° F).

The incinerator system can be integrated with a firetube or watertube waste heat boiler for heat recovery. When the boiler is installed, an induced draft fan draws the hot gases from the incinerator stack, through the boiler, and then to the boiler stack.

Environmental Services Corporation

Although not a manufacturer, the Environmental Services Corporation constructs and operates small resource recovery facilities for municipalities. Currently the company is modifying and testing in Crossville, Tennessee, a system consisting of two modified Farrier, Inc., Model 2500 incinerator modules, each with a capacity of 27.2 Mg/day (30 TPD), and two York-Shipley 350-hp packaged firetube boilers. The principal components modified were the ram loader and the continuous residue removal system. Although not as yet fully operational at the date of this report, the Crossville facility is designed to burn 54.4 Mg/day (60 TPD) of refuse with the following composition: industrial and commercial refuse, 50 percent; rubber waste, 25 percent; and municipal waste, 25 percent. The main building houses the tipping floor, the office, and the front-end processing system consisting of a Saturn 100-hp shredder and automatic feed converyors. The two incinerators are outside and on each side of an attached building enclosing the two boilers.

The primary chamber in each of these incinerators is a substoichiometric combustion unit. The waste is shredded and fed by a conveyor into the hopper of a hydraulic ram feeder. A preset timer control activates the ram injection of waste into the primary chamber. The primary chamber is operated near 1903°C (2000° F) at substoichiometric combustion conditions.

Excessive temperatures are prevented by locking out the feeder ram and by water spraying the hot gases. A blower supplies underfire air through air tubes in the sides of the hearth. The center of the hearth was modified to contain a drag conveyor that transports the residue from the front to the rear of the unit. The ash residue drops into a water sealed pit and is then removed by another drag conveyor to a container.

The secondary chamber is a 1.8m (6-ft)-diameter, 3.6m (12-ft)-long cylinder. A minimum temperature of 871° C (1600° F) is maintained by a burner while the normal operation temperatures, ranging from 982° to 1093° C (1800° to 2000° F), are controlled by modulating the combustion air.

The incineration system is integrated with a fire tube boiler. An induced draft fan draws the flue gases from the exhaust stack, through the boiler, and then back into the stack.

Giery (Pyro-Cone)

The Pyro-Cone incinerator is designed to burn industrial and municipal solid waste. Capacities range from 0.9 to 2.7 Mg/day (1 to 3 TPD). A 0.9 Mg/day (1 TPH) installation to burn municipal waste was constructed in Grafton, Wisconsin, in 1968. The system was designed to recover the heat from the combustion of the municipal waste.

The primary chamber in this incinerator is an excess air combustion unit. A vertical, double door, lock hopper feeds the waste into the primary chamber which contains a rotary cone grate. This chamber is operated at 694° C (1200° F) by regulating the combustion and secondary air and by controlling the refuse feed rate.

The secondary chamber is a vertical, cyclonic flow vessel. Excess air is injected into this chamber to maintain the outlet temperature desired.

The incinerator system can be integrated with a firetube waste heat boiler for heat recovery. An induced draft fan draws the hot gases through the boiler, an air filter, a wet scrubber, and then to the boiler stack.

Kelley

The Kelley incinerators are designed to handle industrial, commercial, and municipal waste. Capacities of the units range from 45.4 to 908 kg/hr (100 to 2000 lb/hr). Municipal installations with capacities of 10.8 to 13.6 Mg/day (12 to 15 TPD) without heat recovery are located in Notingham, Bridgewater, Meredith, Wolfboro, Pitsfield, and Auburn, New Hampshire. Industrial installations with heat recovery are in the following plants: Danskin, Inc., York, Pennsylvania; Xerox Corporation, Columbus, Ohio; John Deere Company, Horicon, Wisconsin; Rockwell International Corp., Marysville, Ohio; Smith Loveless, Lenexa, Kansas; TFC Industries, Omaha, Nebraska; and K. W. Muth Company, Sheboygan, Wisconsin.

The primary chamber in each of these incinerators is a substoichiometric combustion unit. A hydraulic ram feeder pushes the waste into and through the primary chamber. The chamber is operated at 33 percent stoichiometric combustion air and at temperatures between 694° and 871° C (1200° and 1600° F). A burner provides supplemental heat to keep the temperature above 694° C (1200° F). The reduction of the refuse feed rate and the introduction of water sprays keep the temperature below 871° C (1600° F).

The secondary or inspirator chamber is installed as a part of the stack system. This chamber is operated at temperatures cycling between 538° and 1093°C (1000° and 2000° F) by modulating excess air to 150 percent and heat input from an auxiliary burner.

The incinerator system is integrated with a triple-pass firetube waste heat boiler. An induced draft fan draws the hot gases through the boiler in three passes with the last exiting into the incinerator stack. The schematic layout of the incinerator is shown in Section 4.

Lamb-Cargate, Industries Limited

The primary chamber in this incinerator, which is called the Lamb Wet Cell Burner, is a substoichiometric combustion unit. The system was designed to burn moist waste, such as wood, pulp, and saw dust, with a moisture content up to 65 percent. The waste is metered from a storage bin into a cylinder by a variable speed hydraulic motor. The motor speed is regulated to meet the Btu demand of the burning process.

The units have a capacity of 21.8 to 181.4 Mg/day (24 to 200 TPD). A 21.8 Mg/day (24 TPD) unit is in operation in Egen, British Columbia, at the Plateau Sawmills, Ltd. The recovered heat is directed to two lumber drying kilns. A second unit of the same size is firing a pulp flash dryer at a new TMP pulp mill in Karioi, New Zealand. The facility is owned by Winstone Samsung, Inc.

The primary combustion chamber, a vertical vessel, is located above the refuse injection cylinder. A hydraulic ram forces the waste in the cylinder through a hole in the grate that forms the chamber floor. The waste forced into the chamber forms a conical pile which is initially ignited by an auxiliary burner. The chamber is operated at temperatures between 694° and 871° C (1200° and 1600° F) with underfire combustion air preheated to 260° C (500° F). Overfire air is also provided while still maintaining substoichiometric conditions. Near the top of the chamber is a series of air jets whose centrifugal force on the rising hot combustion gases carries the particulates to the outer walls such that the heavier ash and sand particles fall near the edges. The relatively low chamber temperature prevents slagging.

The ash is continuously removed by a Detroit Stoker carrousel system whose rotating grate moves the ash into a double air lock removal system.

The secondary chamber, a vertical refractory vessel, operates under finely controlled excess stoichiometric air conditions. Preheated between the outer shell and the refractory, the combustion air is injected tangentially into the secondary chamber through ports in the inner shell. The vortex caused by the spiralling air completely mixes the combustion gases and the air. The flue gases are between 1093° and 1335° C (2000° and 2500° F). Process demands control the burner, the refuse feed, and the combustion air to maintain the desired air-to-fuel ratio. The burner can function at 10 to 15 percent excess air. A 30-second response time from the low capacity of 52,700 MJ/hr (5 MBtu/hr) to the peak capacity of 26,000 MJ/hr (25 MBtu/hr) makes this unit ideally suited for process heat applications.

Morse Boulger

Morse Boulger makes small substoichiometric incinerators for industries and larger excess air incinerator systems for municipalities. Capacities of the substoichiometric units vary from 45.4 to 2270 kg/hr (100 to 5000 lb/hr). The municipal unit capacities vary from 22.6 to 226 Mg/day (25 to 250 TPD). An industrial system with a fire tube waste heat recovery boiler has been installed in Nassau Hospital in Mineola, New York. New York City has installed four 226-Mg/day (250-TPD) municipal units.

The hydraulically operated ram feeds the industrial waste into the cylindrical primary chamber from a charging hopper. An auxiliary dual-fueled burner located beneath the raised hearth ignites the waste. A blower, also mounted beneath the raised hearth, provides only enough air for substoichiometric combustion in the primary chamber. Since there is no overfire air, entrainment of particulates in the flue gases is minimized. The ash moves through the unit by action of the charging ram and falls through a drop chute in the floor at the rear of the unit. The back of the primary chamber swings open to permit access for inspection, repairs, and removal of bulk ash.

The temperature in the primary chamber is maintained at 760° C (1400° F) Lockout of the feed system prevents over temperatures. The cylindrical secondary chamber mounts on top of the primary chamber. Excess combustion air is injected tangentially. A secondary dual burner system provides temperature control at 927° C (1700° F). Both chambers are lined with fire brick to maximize the time between refractory repairs. Packaged boilers and heat exchangers can be provided for recovery of energy. An induced draft fan draws the flue gases through the heat recovery unit and then to the incinerator stack.

The municipal unit is an excess air incinerator. A drop chute feeds the waste into a rectangular primary chamber. Cascading grates move the waste through the combustion chamber. A blower provides underfire air for cooling the grates and for combusting most of the organics in the waste. Overfire air is provided for gas combustion. A conveyor removes the ash through the floor of the unit.

The burning gases from the primary chamber flow under baffles and over an archway to the parallel secondary chamber. An induced draft fan then draws the gases through a series of cyclonic water scrubbers to lower the particulate level to emission standards. For heat recovery, the incinerators can be integrated with boilers and other suitable heat exchangers.

Scientific Energy Engineering

The Scientific Energy Engineering incinerator is designed to burn shredded municipal solid waste. The capacity of this system ranges from 68 to 136 Mg/day (75 to 150 TPD). An experimental 226.8 Mg/day (250 TPD) unit in Jacksonville, Florida, has been operational for 2 years. The facility is currently undergoing testing and evaluation.

The primary chamber in this incinerator is a substoichiometric combustion unit. An auger conveyor system feeds the refuse into a horizontal cylindrical chamber, moves the waste through the chamber, discharges the residue into a water quench tank, and conveys the discharged residue from the tank to a truck-loading site. The primary chamber is supplied with about 40 percent of stoichiometric air to maintain a temperature of 815° C (1500° F).

Excess air is injected into the secondary chamber to maintain a temperature between 982° to 1093° C (1800° and 2000° F).

Although the prototype system does not include heat recovery equipment, future systems will incorporate such equipment.

Simonds Company

The Simonds incinerators are designed to burn solid and liquid wastes from commercial and industrial sites and pathalogical wastes from hospitals. Capacities range from 45.4 to 1335 kg (100 to 2500 lb) per hour. Hospital installations with waste heat recovery are located at Boca Roton, Daytona Beach, Pensacola, and Orlando, Florida; Charleston, South Carolina; and Donnelson, Tennessee. An industrial facility at Plough, Incorporated, Memphis, Tennessee, has a burning capacity of 908 kg (2000 lb) per hour. This facility has waste heat recovery.

In the Simonds units the waste is fed from a hopper into a rectangular substoichiometric primary chamber by a hydraulically operated ram. In nearly all the installations, the residue is removed manually in batches through a clean-out door. A recently designed automatic system consists of a series of rams that enter the primary chamber and push the residue out of the chamber through an air lock door.

The primary chamber is lined with castable refractory. A blower supplies sufficient air to allow combustion of the waste under stoichiometric conditions. The air is introduced into the primary chamber through manifolds along both sides of the flat hearth. Temperature is maintained at about 787° C (1450° F) by regulating the airflow and controlling the introduction of waste.

A smaller rectangular secondary chamber is located on top of the primary chamber. A modulating burner maintains a minimum temperature at 787° C (1450° F). Sufficient air is introduced to ensure completion of the combustion process under excess air conditions.

The system is integrated with heat recovery equipment. A prefabricated module for either hot water generation or steam generation is available.

An induced draft fan draws gases from the incinerator breeching to and through the heat recovery module, and then through the boiler exhaust stack.

U.S. Smelting Furnace Company

The units manufactured by this firm are called Smokatrol incinerators. They are designed to burn industrial and commercial waste. Capacities of the units range from 45.4 to 1335 kg (100 to 2500 lb) per hour. The firm has just begun to actively market the newly acquired Smokatrol line of incinerators.

The primary chamber in each of these incinerators is a substoichiometric combustion unit. A hydraulic ram feeder pushes the refuse into and through the primary chamber. This chamber is a horizontal cylindrical vessel with a burner for start-up firing and for maintaining combustion temperatures of approximately 815° to 871° C (1500° to 1600° F). The temperature is also maintained by controlling the refuse feed rate through a temperature lock-out. Unmodulated combustion air enters the chamber through perforated tubes in the floor. The ash at the exit end of the chamber falls through a drop chute into a water quench pit (which forms the air seal) where a drag conveyor pulls it into a drop box.

The secondary chamber is a horizontal cylindrical vessel with baffles to promote combustion. This chamber is operated at temperatures about 1093° C (2000° F) by modulating the air supply.

The incinerator system is integrated with a triple-pass firetube waste heat boiler. An induced draft fan pulls the hot gases through the boiler in three passes with the last exiting into the incinerator stack.

Wasburn and Granger

The incineration units are custom-designed to burn municipal solid waste. Under construction in Mayport, Florida, is a unit for the Navy that will burn 1.8 Mg/hr (2 TPH) of municipal waste and also have heat recovery.

The primary chamber in each of these incinerators is a substoichiometric combustion unit. In the large systems, a ram feeder pushes the refuse into and through a rectangular primary chamber. Air flows at a constant rate into this chamber with the burners modulated to maintain a temperature of 538° C (1000° F). The ash is removed continuously through a vertical drop chute at the end of the chamber. A horizontal ram at the bottom of the chute pushes the ash through an air lock into a container.

The secondary chamber receives air at a constant flow rate. Chamber temperature is maintained at 760° C (1400° F) by modulating a burner.

The incinerator system can be integrated with heat recovery equipment.

SUMMARY

In summary of the foregoing 17 incinerator system sources, the following presents the five incinerator system categories along with the corresponding sources and representative illustrations for each category.

(1) Two horizontal cylindrical chambers with one above the other, as manufactured by Environmental Control Products, Comtro, Morse Boulger, Econo-Therm, Kelley, Consumat, and Smokatrol (see Figure 2).

(2) Two horizontal rectangular chambers with one above the other, as manufactured by Washburn & Granger, Basic, and Simonds (see Figure 3).

(3) Two vertical cylindrical chambers with one above the other, as manufactured by Burn-Zol and Lamb-Cargate (see Figures 4 and 5).

(4) A rotary primary chamber or fixed primary chamber with a rotary grate or auger and a fixed secondary chamber, as manufactured by Scientific Energy Engineering, Giery, and C. E. Bartlett (see Figures 6, 7, and 8).

(5) Two horizontal rectangular chambers with one after the other, as manufactured by Clear Air (see Figure 9).

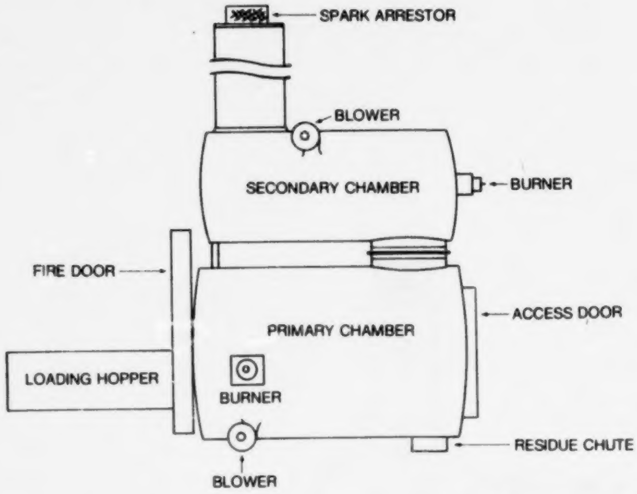

SPARK ARRESTOR
BLOWER
SECONDARY CHAMBER
BURNER
FIRE DOOR
ACCESS DOOR
PRIMARY CHAMBER
LOADING HOPPER
BURNER
RESIDUE CHUTE
BLOWER

Figure 2. Configuration of two horizontal cylindrical chambers with one above the other.

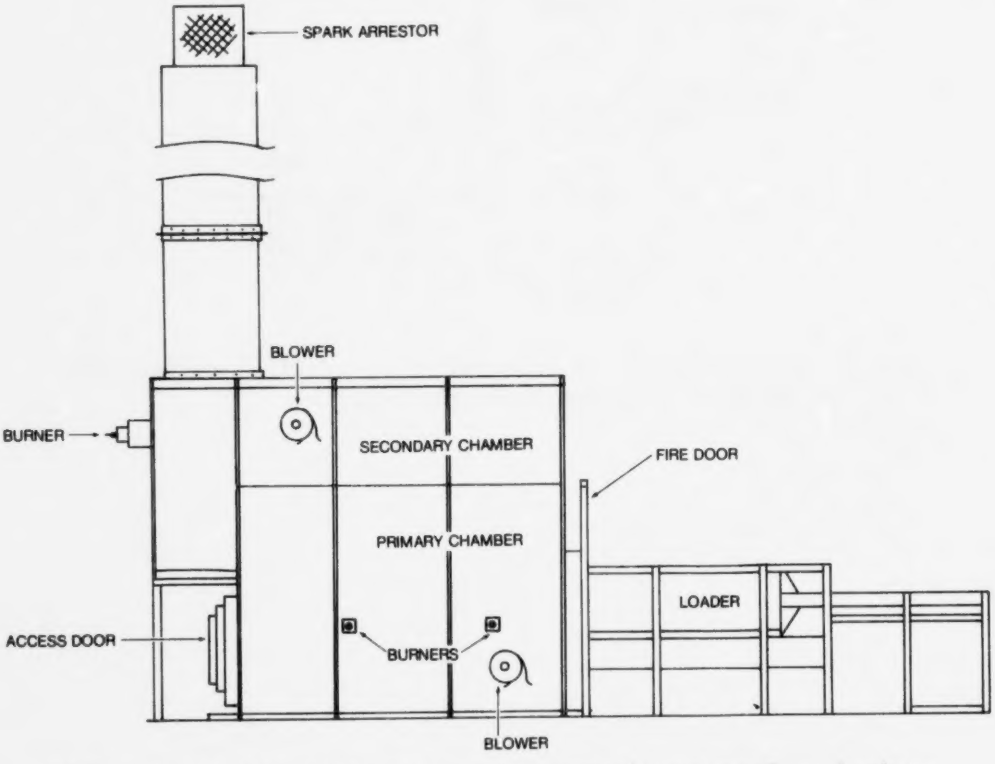

SPARK ARRESTOR
BLOWER
BURNER
SECONDARY CHAMBER
FIRE DOOR
PRIMARY CHAMBER
LOADER
ACCESS DOOR
BURNERS
BLOWER

Figure 3. Configuration of two horizontal rectangular chambers with one above the other.

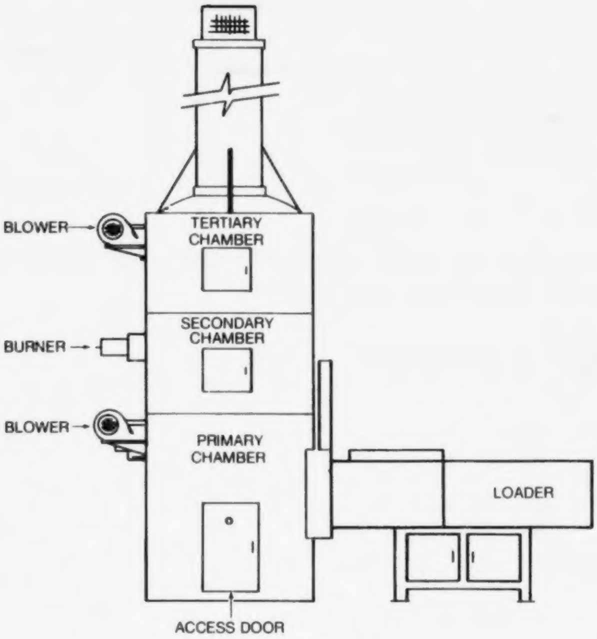

BLOWER
TERTIARY CHAMBER
SECONDARY CHAMBER
BURNER
BLOWER
PRIMARY CHAMBER
LOADER
ACCESS DOOR

Figure 4. Configuration of Burn-Zol's two vertical cylindrical chambers with one above the other.

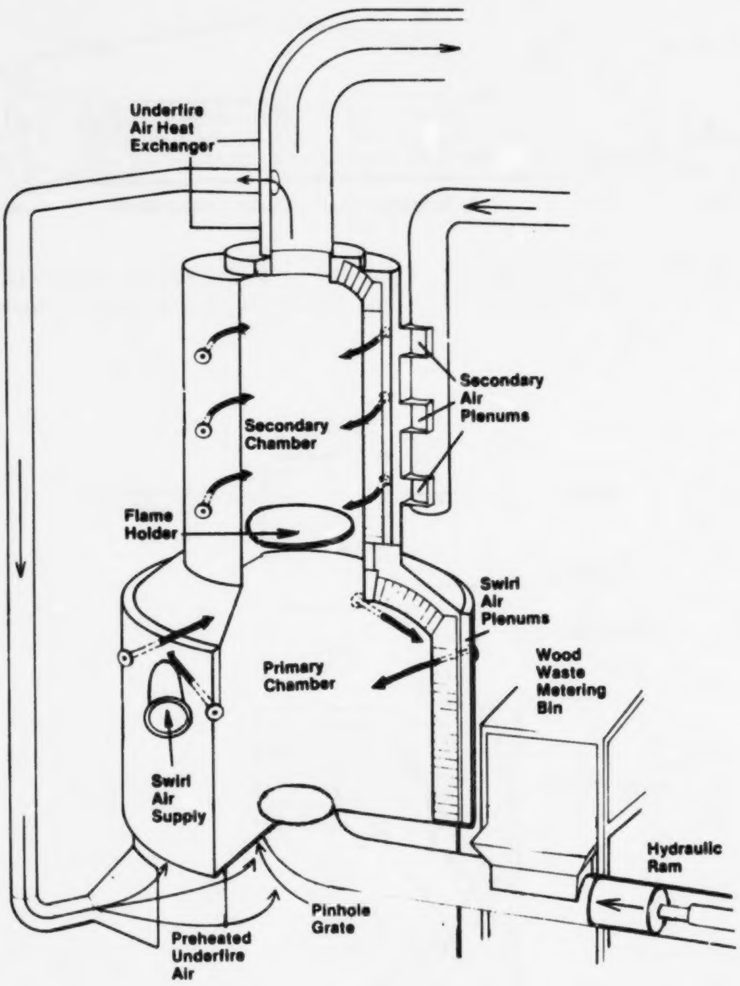

Underfire
Air Heat
Exchanger
Secondary
Air
Plenums
Secondary
Chamber
Flame
Holder
Swirl
Air
Plenums
Primary
Chamber
Wood
Waste
Metering
Bin
Swirl
Air
Supply
Hydraulic
Ram
Pinhole
Grate
Preheated
Underfire
Air

Figure 5. Configuration of Lamb-Cargate's two vertical cylindrical chambers with one above the other.

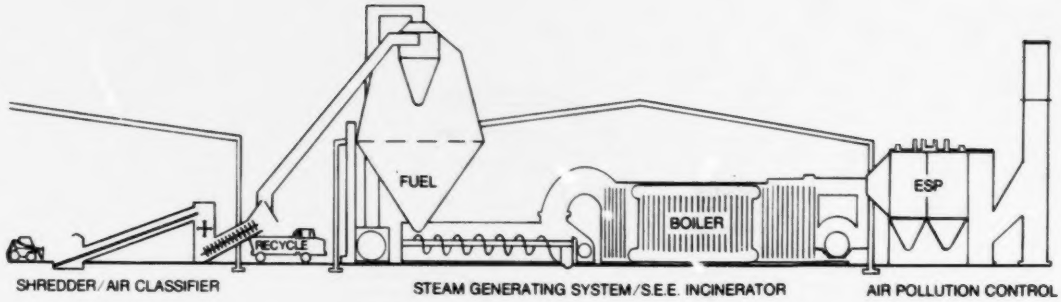

FUEL
BOILER
ESP
RECYCLE
SHREDDER/AIR CLASSIFIER
STEAM GENERATING SYSTEM/S.E.E. INCINERATOR
AIR POLLUTION CONTROL

Figure 6. Configuration of Scientific Energy Engineering's incinerator with an auger in the primary chamber.

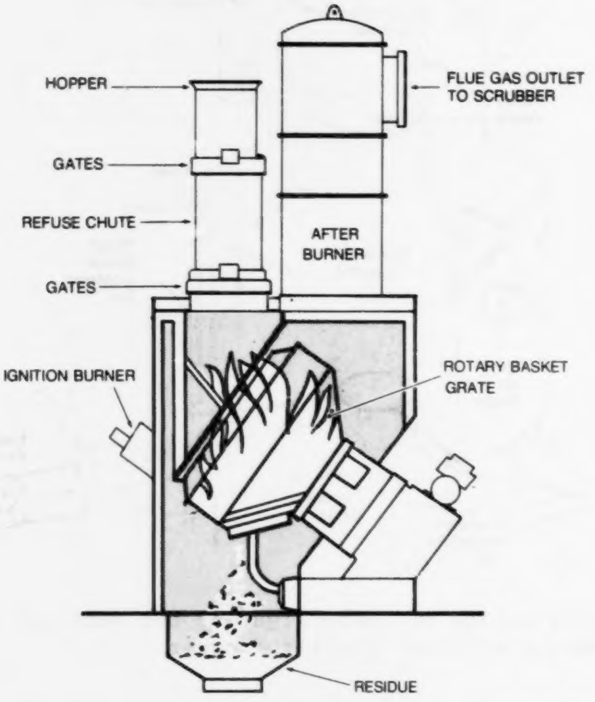

HOPPER
GATES
REFUSE CHUTE
GATES
FLUE GAS OUTLET TO SCRUBBER
AFTER BURNER
IGNITION BURNER
ROTARY BASKET GRATE
RESIDUE

Figure 7. Configuration of Giery's incinerator with a rotary grate in the primary chamber.

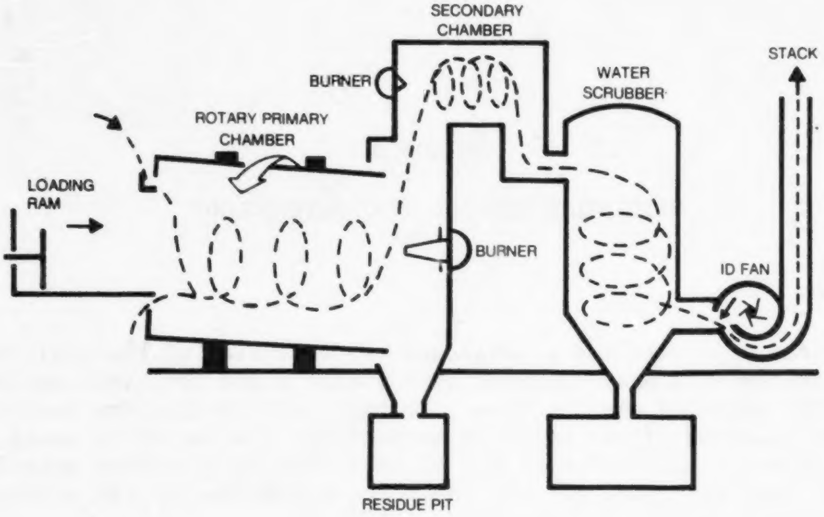

SECONDARY CHAMBER
STACK
BURNER
WATER SCRUBBER
ROTARY PRIMARY CHAMBER
LOADING RAM
BURNER
ID FAN
RESIDUE PIT

Figure 8. Configuration of C. E. Bartlett's incinerator with a rotary primary chamber.

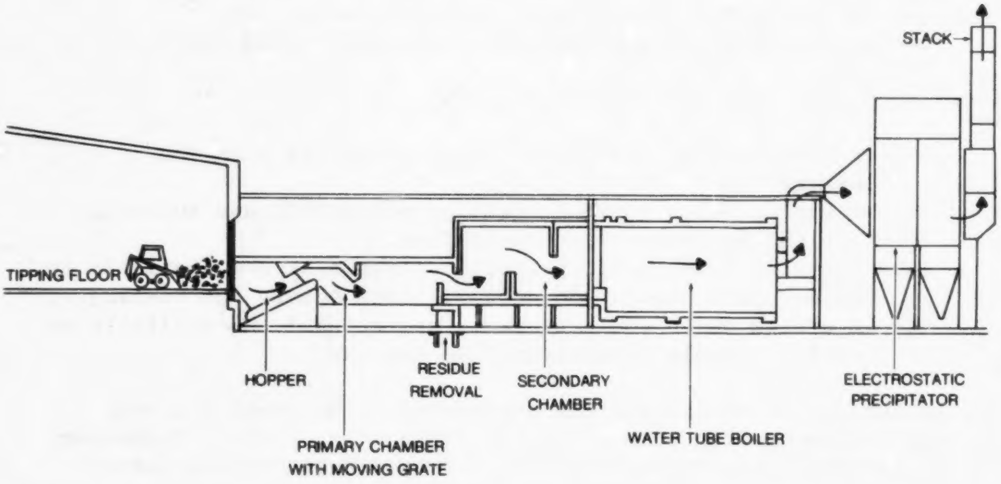

STACK
TIPPING FLOOR
HOPPER
RESIDUE REMOVAL
SECONDARY CHAMBER
ELECTROSTATIC PRECIPITATOR
WATER TUBE BOILER
PRIMARY CHAMBER WITH MOVING GRATE

Figure 9. Configuration of Clear Air's incinerator-heat recovery system with two horizontal rectangular chambers aligned one after the other.

SECTION 3

SITE SELECTION AND TEST METHODOLOGY

SITE SELECTION

The program objective was to evaluate the potential of the small modular incinerator system with heat recovery as a viable means for handling the municipal solid waste of small cities. To this end, the program called for (1) the identification of all existing incinerator systems which would meet four basic criteria, (2) the screening of the identified systems according to an additional four criteria, and (3) the selection of two of the systems meeting all eight criteria for detailed evaluation.

The initial four criteria to identify candidate systems were as follows:

(1) A system whose capacity per unit and per system were under 45.3 and 90.7 Mg/day (50 and 100 TPD), respectively.
(2) A system with integrated heat recovery equipment.
(3) A system representative of current technology.
(4) A system burning principally municipal solid waste.

The second four criteria were as follows:

(1) A system whose management would cooperate with the evaluation.
(2) A system which would be readily accessible and suitable for the system evaluation testing.
(3) A system which would be fully operational and available to gather maintenance and economic data before the testing.
(4) A system which would be fully operational and available to collect sample data during the testing.

The investigation of the systems according to the eight criteria required the following four steps. In the first step, Systems Technology Corporation (SYSTECH) identified the sites of candidate systems through consultations with the manufacturers of the 17 systems discussed in Section 2. In the second step, SYSTECH engineers visited the principal sites of the candidate systems to analyze and document their potential for meeting the eight criteria. With the information collected during the site visits, the third step involved rating the candidate sites according to the degree to which they met each of the eight criteria. The fourth step, the selection of two sites to be evaluated, required approvals from the site management, the EPA, and the incinerator manufacturer.

The site management had to permit SYSTECH to install test equipment and to conduct the tests during normal operating conditions. The Environmental Protection Agency (EPA) approval was required to confirm that the selected sites met the criteria specified in the contract. The incinerator manufacturer had to provide equipment layout details, manufacturing and design information, and operational data. As will be discussed, the four steps were performed twice in two separate investigations.

In the first investigation, five municipal sites were identified as evaluation candidates and were rated in the given order according to their meeting the criteria:

(1) North Little Rock, Arkansas, with a Consumat facility.
(2) Crossville, Tennesse, with a Farrier facility.
(3) Siloam Springs, Arkansas, with a Consumat facility.
(4) Blythville, Arkansas, with a Consumat facility.
(5) Groveton, New Hampshire, with an Environmental Control Products facility.

Of the five sites, only North Little Rock had a facility which satisfactorily met all criteria. This facility has four Consumat 22.7 Mg/day (25 TPD) modules with two heat recovery modules. Each heat recovery module can generate 4540 kg/hr (10,000 lb/hr) of steam at 150 psi for delivery to a nearby manufacturer.

Therefore, to acquire a second site for the comprehensive evaluation, the EPA modified the requirement for the type of refuse burned to include industrial waste. Accordingly, a second investigation was conducted with the four steps applied to incinerator systems burning industrial waste. As a result, four additional sites were identified as evaluation candidates. They were visited for the preliminary candidate evaluation and rated in the given order according to their meeting the eight criteria:

(1) Rockwell International, Marysville, Ohio, with a Kelley facility.
(2) Moore Business Forms, Homesdale, Pennsylvania, with a Comptro facility.
(3) John Deere, Dubuque, Iowa, with a Consumat facility.
(4) Pentagon, Washington, D.C., with a Consumat facility.

The last two sites were given the lowest ratings principally to avoid evaluating sites with the same type of equipment as the municipal facility.

Of the four sites burning industrial waste, Rockwell International was selected as the second site to be evaluated. The facility at this site includes a Kelley incinerator, a York-Shipley firetube boiler, and a Trane absorption chiller. Capable of burning 545 kg/hr (1200 lb/hr) of Type 0 industrial waste, the facility produces hot water whose thermal energy is used for both heating and cooling the plant's main building.

TECHNICAL EVALUATION

The technical evaluation was based on the results from the three field tests at each of the two selected sites. The North Little Rock facility was first tested during the week of March 20 to 24, 1978. The units were then not at full capacity and were still undergoing equipment modification. The second field test was conducted during the week of May 22 to 26, 1978. The units were still not at operating capacity and were undergoing further changes. The third field test was held during the week of October 9 to 13, 1978, when the units were operating near capacity and the changes had been completed. The Marysville facility was first tested during the week of April 24 to 28, 1978. During this period refractory repairs interfered with the stack emissions testing. In addition, the system did not operate under steady-state conditions because of mild weather and the consequent low heating demand. The second field test was held during the week of July 17 to 21, 1978, when the system was operating in a steady-state condition with daily burndown periods. The third test was conducted during the week of August 21 to 25, 1978, when the daily waste loading varied widely.

The efficiencies of refuse combustion and of the incineration system were determined and analyzed. The efficiency of the steam generating boiler at North Little Rock was determined by two methods: (1) the input-output method which is expressed as

$$\eta = \frac{\text{useable energy out}}{\text{total energy in}}$$

and (2) the heat loss method which is expressed as

$$\eta = 1 - \frac{\text{sum of heat losses}}{\text{total energy in}}$$

According to ASME codes, the efficiency of the hot water boiler at Marysville was determined only by the heat loss method.

The heat losses in the following sources or causes were negligible and therefore not considered in the energy balance or efficiency calculations: (1) unburned carbon monoxide, (2) unburned hydrocarbons, (3) radiation to sump plus latent heat lost in the fusion of slag, (4) sensible heat in flue dust, and (5) heat removed by cooling water around the sump and air tubes (this water was part of the boiler make-up water heating system).

Both methods required measuring or determining the following: the quantity and heating values of the refuse and residue, the auxiliary fuel used, the amount and enthalpy of the steam generated, and the heat losses such as those due to radiation, convection, and sensible heat in the flue gas.

A mass balance was completed to verify the accuracy of these data so that the data could be validly used in the energy efficiency and balance calculations. In the mass balance, the mass inputs to the system were calculated and compared with the measured mass outputs from the system. In the combustion gas balance, the measured inputs were analyzed to determine their carbon, hydrogen, oxygen, nitrogen, sulfur, ash (inert), and water components. The total mass of these components was compared with the measured mass exiting the stack in the flue gas. In the energy balance, the measured input energies were compared with the measured output energies. While the input and output values in each of the three balances should be equal, values close to equality, i.e., less than a 5 percent difference between them, are normally the optimum results.

As mentioned, the most continuous and stable operating conditions were during the third test period at the North Little Rock facility and during the second test period at the Marysville facility. Therefore, except for some test period comparisons, the technical evaluation for the two facilities is based on the optimum test period for each. Appendix A presents the technical evaluation data for the other two test periods at each site.

ENVIRONMENTAL EVALUATION

Introduction

The effects of the incinerator-heat recovery operation on the environment, specifically the atmosphere, the discharged process water, the landfills for refuse disposal, and the plant areas were evaluated. At each of the two plant sites, these four environments were monitored and analyzed during three periods of normal operation. Table 3 summarizes the environmental aspects monitored and the method used to analyze each.

Affected Environments

Atmosphere--

The stack emissions monitored were particulates, heavy metals (in both particulate and vapor form), and the following gases and vapors: chlorine, fluorine, sulfur and nitrogen oxides, hydrocarbons, and the standard combustion products (oxygen, carbon monoxide, and carbon dioxide). Emission samples were collected from both the exhaust stack and the ambient area around the plant.

The mass flow rate and chemical composition of the particulate heavy metals and some of the gases and vapors were investigated by a modified EPA Method 5 train which is illustrated in Figure 10 and described in the Federal Register of December 23, 1971. As shown in this figure, the train included a filter to capture particulates and three impingers to capture the gases and vapors. The first impinger, which contained hydrogen peroxide, scrubbed out most of the metals that were in vapor form. Then the second impinger contained a dilute nitric acid silver nitrate solution to capture the gases and vapors that passed through the first impinger, and the third impinger was empty.

The mass of the particulates captured on the filter was weighed and then divided by the recorded volume of gas sampled to yield the particulate mass concentration per gas volume. In addition, these particulates were analyzed for chemical composition. The impinger solutions were analyzed for concentrations of sulfur dioxide, chlorine, fluorine, and water vapor.

TABLE 3. ENVIRONMENTAL ELEMENTS SAMPLED WITH SAMPLER AND ANALYSIS TYPE FOR EACH

Element sampled	Sampler	Analysis
1. **Particulates**	(a) Filter in modified EPA Method 5 train	(1) particulate concentration
	(b) 7-stage cascade impactor	(1) particulate size distribution
2. **Flue gases**	(a) Impinger solution in modified EPA Method 5	(1) metals concentration (2) chlorine concentration (3) fluorine concentration (4) moisture concentration (5) sulfur dioxide concentration
	(b) Tri-gas monitor	(1) nitrogen dioxide concentration (2) oxygen concentration (3) sulfur dioxide concentration
	(c) Orsat analyzer	(1) oxygen concentration (2) carbon monoxide concentration (3) carbon dioxide concentration
	(d) Tedlar bag sampler	(1) hydrocarbon composition and concentration
	(e) Infrared analyzer	(1) carbon dioxide concentration (2) carbon monoxide concentration
3. **Ambient air**	(a) Respirable fraction personnel sampler	(1) fugitive dust levels (2) viable organism concentration
	(b) Staff monitors	(1) odor
	(c) Hand-held Ecolyzer	(1) carbon monoxide concentration
	(d) Sound-level meter	(1) noise levels
4. **Water**	(a) Manual grab sampler	(1) chemical composition (2) biological organisms (3) physical properties

A wet-catch sample of the stack particulate was also taken by the modified Method 5 gas train. All three impingers were filled with distilled water. The vapors drawn through the water condensed and the particulates went into solution. The impinger water was then evaporated and the weight of the remaining solids was added to the filter particulate weight to determine the total particulate weight.

To determine the size distribution of the particulates, a seven-stage inertial cascade impactor was inserted in the gas stream (see Figure 11). The weight of the particulates captured on each stage provided the data for computing the particulate size distributions.

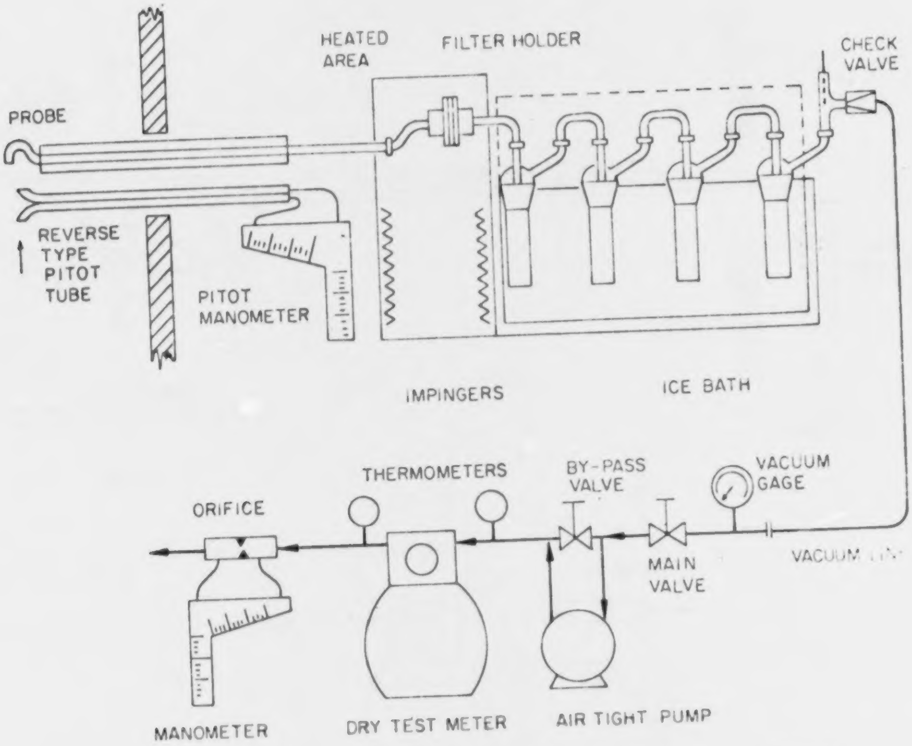

HEATED AREA
FILTER HOLDER
CHECK VALVE
PROBE
REVERSE TYPE PITOT TUBE
PITOT MANOMETER
IMPINGERS
ICE BATH
THERMOMETERS
BY-PASS VALVE
VACUUM GAGE
ORIFICE
MAIN VALVE
VACUUM LINE
MANOMETER
DRY TEST METER
AIR TIGHT PUMP

Figure 10. Schematic of modified Method 5 gas train.

The oxides of nitrogen and sulfur in the stack emissions were analyzed by a continuously recording TSI Monitor and by EPA wet chemistry methods. The TSI Monitor alternately drew samples from the boiler outlet and the exhaust stack. Incorporating electro-chemical cells, the monitor was daily calibrated against standard gases by EPA wet chemistry methods.

The hydrocarbons in the C_1 to C_6 ranges were analyzed by periodically drawing flue gas samples from the boiler exhaust stack and passing them through a gas chromatograph. The monitoring and analysis of the hydrocarbons in the C_7 to C_{12} ranges is described in the discussion of the EPA Level One analysis.

An Orsat analyzer continuously monitored stack-drawn flue gases for the analysis of oxygen, carbon monoxide, and carbon dioxide gases. Two Beckman infrared analyzers also continuously monitored stack-drawn gases to determine the carbon monoxide and carbon dioxide levels in the flue gases.

Opacity was measured by a Leads & Northrup single-pass transmissometer which spanned the stack and was calibrated with neutral density filters.

Attempts to measure the particulate resistivity in the stack by a WAHLCO resistivity probe assembly failed because of the small particulate size which would not collect in the sampling cyclone.

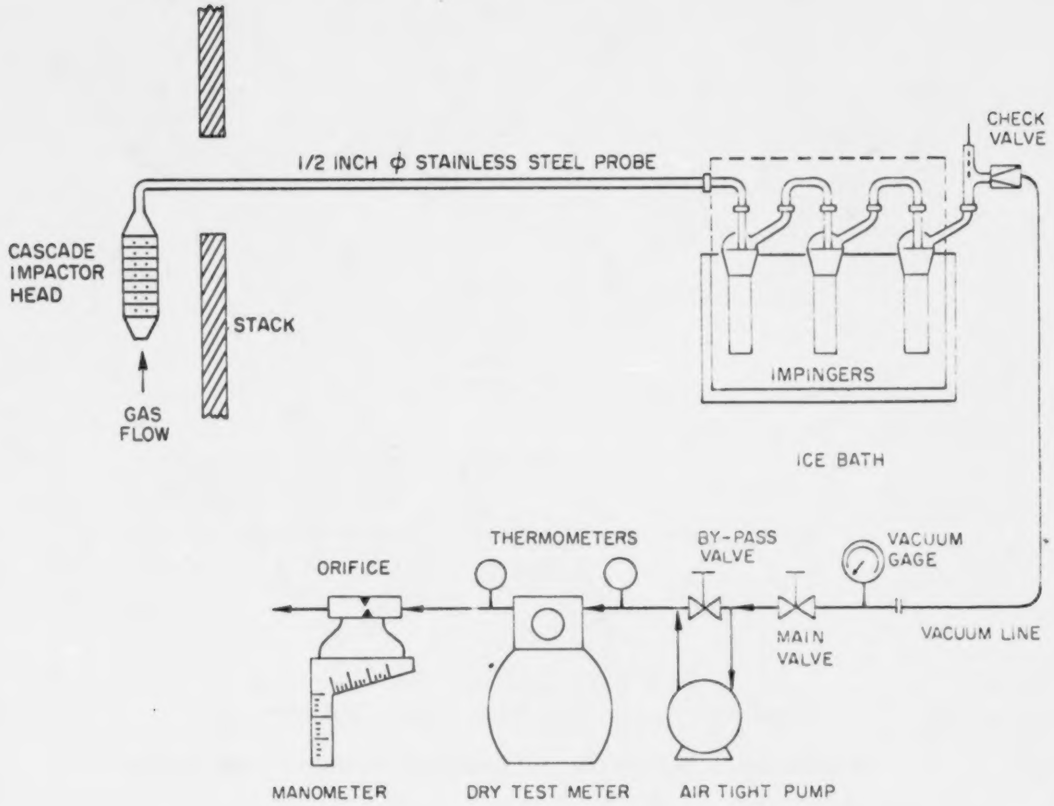

1/2 INCH ϕ STAINLESS STEEL PROBE
CHECK VALVE
CASCADE IMPACTOR HEAD
STACK
GAS FLOW
IMPINGERS
ICE BATH
THERMOMETERS
BY-PASS VALVE
VACUUM GAGE
ORIFICE
MAIN VALVE
VACUUM LINE
MANOMETER
DRY TEST METER
AIR TIGHT PUMP

Figure 11. Schematic of seven-stage cascade impactor.

Process Water--

Of the process water discharged from an incinerator-heat recovery unit, two effluents could have high pollution levels: (1) water pumped from the residue removal sumps and (2) water used to clean the plant and equipment. Consequently, the parameters monitored and evaluated in these effluents included flow rate, pH content, temperature, total coliform, BOD, COD, suspended solids, total solids, and chemical composition.

Landfills for Waste Disposal--

Two plant process streams, combustion residue and bulky refuse rejects, could adversely affect the landfills used for their disposal. Accordingly, to determine the leachate characteristics of the residue, landfill conditions were simulated by preparing laboratory lysimeters in which residue samples were deposited and controlled amounts of moisture were added at regular intervals.

After the leachate had been formed and filtered, the filtrate was analyzed for material content (iron, copper, cadmium, nickel, lead, chrome, fecal strep, total coliform, Cl, ORP, TDS, and TS) and qualities (color, conductivity, density, hardness, odor, pH, COD, and TOC).

Plant Areas--

The ambient elements and conditions monitored inside the plant were fugitive dust, carbon monoxide emitted by the incinerators and vehicles, odors, and noise.

To investigate the fugitive dust, the air was sampled at selected positions by a respirable fraction personnel sampler. The dust captured in the filters of this sampler was analyzed for dust concentrations and viable biological organisms according to the methods recommended in the American Public Health Association (APHA) Standard Methods, 14th Edition. Odors were investigated to determine their source and degree of offensiveness. Carbon monoxide levels were measured by a hand-held Ecolyzer monitoring instrument. Noise levels were measured at sufficient points to prepare a noise contour map that could indicate areas where the levels exceeded 90 dBA. In addition to the in-plant readings, the noise levels at the property boundaries were measured to compare them with the noise limits prescribed by local ordinances.

The ambient air sampling outside the plant is described in the discussion of the EPA Level One analysis.

EPA Level One Type of Analysis

Analysis Rationale and Procedure--

The EPA Level One type of analysis is designed to detect the presence of organic and inorganic contaminants in the mass emissions.

As the first of three levels of sampling and analyzing, Level One has a threefold objective: (1) to yield preliminary environmental data, that is, broad approximations of the concentrations and emission rates of inorganic elements, selected inorganic unions, and organic compounds in particular categories; (2) to identify pollution sources; and (3) to assign priorities to elements that should be investigated further. Level Two further defines the organic and inorganic elements, and Level Three defines the Level Two data to provide information leading to the design and development of control devices.

In the current program, the Level One sampling and analysis methods were adapted to specially investigate the emissions that have a high potential for adversely affecting the environment.

According to the Level One analysis methods, the inorganic elements were analyzed by spark source mass spectrometry, wet chemistry, and gas chromatography of compounds in the C_7 to C_{12} ranges. The organic elements were analyzed by low-resolution mass spectrometry, liquid chromatography, infrared analysis, and gas chromatography of compounds in the C_1 to C_6 and C_7 to C_{12} ranges.

Elements Sampled--

Outside Ambient Air--At about 300-meter distances both upwind and downwind of the plant, the air samples were taken by a high-volume sampler to analyze the particulate size distributions and chemical compositions. A sorbent trap was also used to analyze the gas chemical composition.

A high-volume sampler was set up twice for a 24-hour period with a 570-ℓpm (20-cfm) draw rate to sample 816 m^3 (28,800 cubic feet) of air each time. The first setup with an Anderson impactor head installed was to collect particulates for the size distribution analysis. The second setup with an 8- × 10-in. filter installed was to collect particulates for the chemical analysis.

The sorbent trap, which contained XAD-2 resin, was installed in a weatherproof box with only the sampling port protruding, as shown in Figure 12. A vacuum pump drew air through the trap.

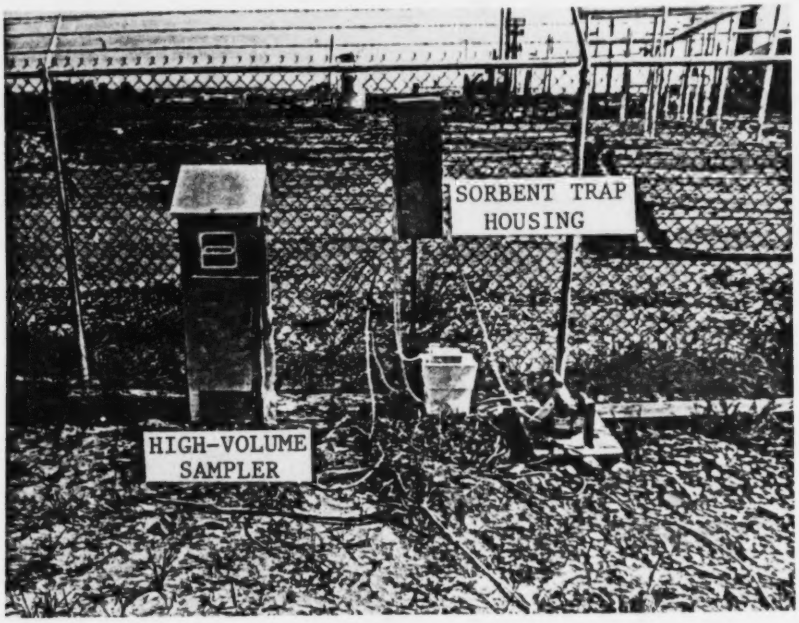
Stack Emissions--The flue gases in the boiler exhaust stack were sampled with Tedlar bags for off-site chemical analysis. They were also sampled by the filter in the modified EPA Method 5 train and by the resin sorbent trap installed in series with the filter in the Method 5 train. Figure 13 illustrates the modified EPA Method 5 train with the trap installed.

Process Water--The process water was sampled only at the North Little Rock plant since the Marysville incinerator-heat recovery unit does not discharge any water.

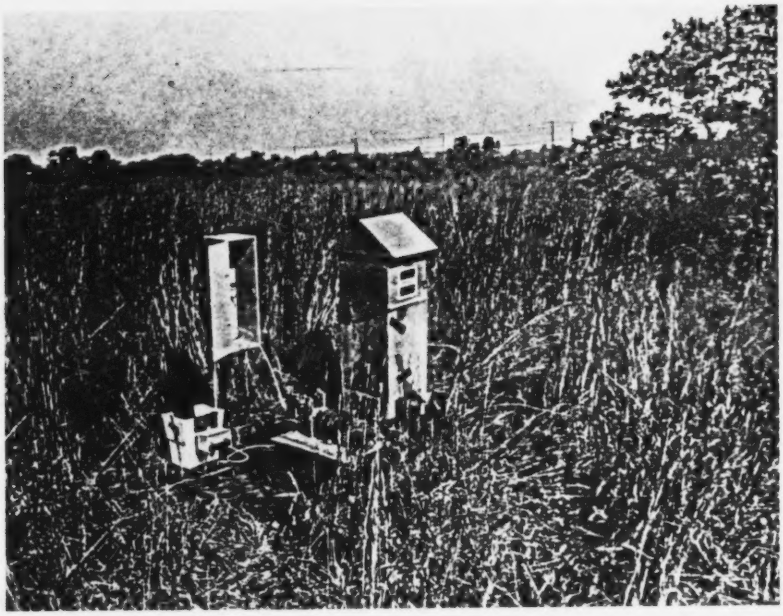
The water samples were analyzed for chemical and bacteriological composition according to the methods recommended in the APHA Standard Methods, 14th Edition.

Residue and Leachate--As described in Section 4, the incinerator residue was sampled daily. Both the original samples and the leachate formed from these samples were analyzed for chemical composition. The leachate was formed in two different runs. In one run, the residue was leached at ambient temperature with distilled water and a phosphate buffer on a vibrating table for 3 days. The phosphate buffer (H_2PO_4 - KH_2 - PO_4) was added to lower the pH to 5.0 for rain water simulation. In the other run, the residue was leached as in the first run but with only distilled water with a pH of 5.5. This was done to determine the interference effects of the phosphate buffer. After the leachate from both runs was filtered, the filtrate was analyzed for chemical composition.

In addition, the landfill-deposited residue was inspected to determine its leaching characteristics.


SORBENT TRAP HOUSING
HIGH-VOLUME SAMPLER

Downwind assembly at North Little Rock



Upwind assembly at North Little Rock

Figure 12. View of ambient air sorbent trap assembly.

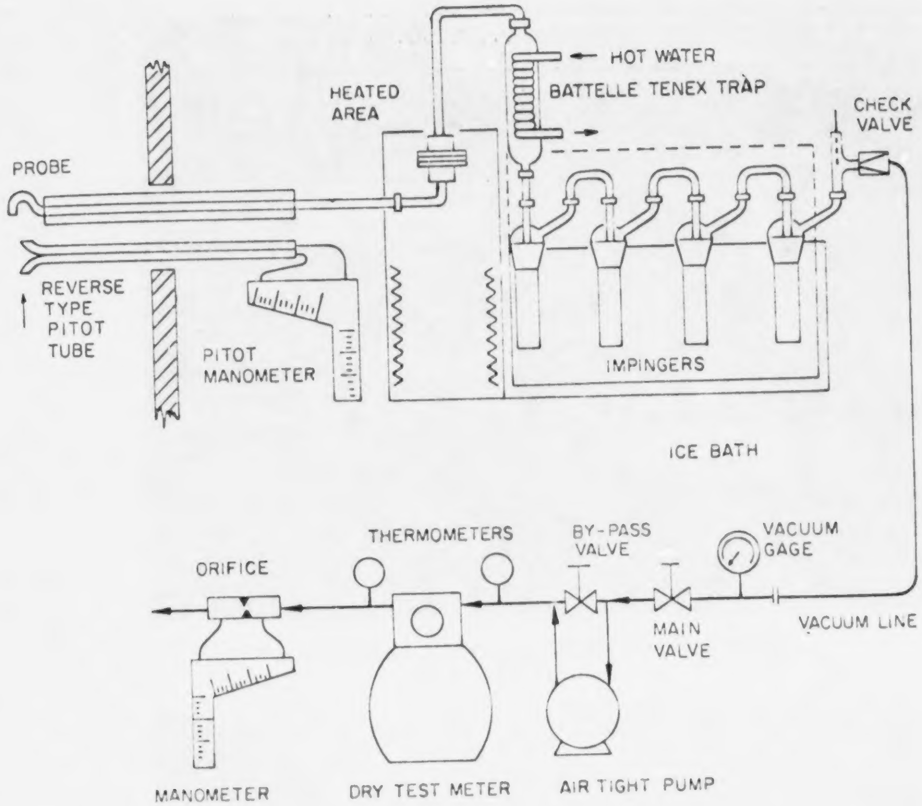

HOT WATER
BATTELLE TENEX TRAP
HEATED AREA
CHECK VALVE
PROBE
REVERSE TYPE PITOT TUBE
PITOT MANOMETER
IMPINGERS
ICE BATH
THERMOMETERS
BY-PASS VALVE
VACUUM GAGE
ORIFICE
MAIN VALVE
VACUUM LINE
MANOMETER
DRY TEST METER
AIR TIGHT PUMP

Figure 13. Sketch of stack sorbent trap assembly.

ECONOMIC EVALUATION

Arthur Young & Company, an international accounting firm subcontracted to perform the basic economic evaluation, defined the costs associated with the construction and operation of the North Little Rock and Marysville facilities. On the basis of these costs, the annual costs of the various plant operating and system aspects were projected. With some specific deviations in which costs are presented in accordance with the generally accepted accounting principles (GAAP), this evaluation includes the accounting format prescribed by the Office of Solid Waste Management Programs.

The evaluation was designed to present a detailed accounting of (1) capital costs, (2) operating and maintenance costs, (3) revenues, and (4) net operating costs.

The capital cost categories are land, site preparation, design, construction, real equipment, other equipment, other costs, and modifications. The operating and maintenance cost categories are salaries, employee benefits, fuel, electricity, water and sewer, maintenance, replacement equipment, residue removal, chemicals, interest, depreciation, and other overhead. The revenue categories are steam revenue and tipping fees. In addition to line costs, the following tables include (1) total capital investment, (2) total operating cost per Mg of refuse processed, (3) total operating and maintenance costs, (4) total revenues, and (5) net operating costs.

The economic evaluations for the two facilities have major sections as follows: (1) accounting system, (2) capital costs and their financing, (3) operating and maintenence costs, (4) revenues, (5) net operating costs, and (6) summary.

SECTION 4

OVERVIEW OF FACILITIES AND THEIR EVALUATIONS

EVALUATION OVERVIEW

The current program was designed to evaluate small modular incinerators in terms of operational data that would reflect the state of the art of their technologies. Since incinerators burning municipal solid waste have different operating conditions than those burning industrial waste, a unit of each type was separately evaluated. Although the two evaluations are documented together, they are not compared since each typifies a discrete set of conditions. Consequently, the reader is cautioned against drawing any comparative conclusions.

The two selected facilities were each tested over three 1-week periods to gather data for technical, environmental, and economic evaluations. The technical evaluation consisted of (1) refuse and residue analyses, (2) efficiency analyses of the incinerator and the heat recovery boiler, (3) an operational data summary, and (4) a maintenance data summary. For each facility, a mass balance was prepared for the weekly field test with the most continuous and stable operating conditions to verify the accuracy of the data used in the energy efficiency and balance calculations. In the mass balance, the mass inputs to the system were calculated and compared with the measured mass outputs from the system. In the energy balance, the measured input energies were compared with the measured output energies. While the input and output values in each of these balances should be equal, values close to equality, i.e., less than a 5 percent difference between them, are normally considered the best achievable.

The environmental evaluation consisted of analyses of the stack flue gases, the residue, the process water, and the general plant environment. In addition, an EPA Level 1 type of anlysis was designed to identify the organic and inorganic elements in the system emissions. The EPA-recommended analysis methods and sampling techniques were applied to investigate the emissions that had a high potential for adversely affecting the environment. The economic evaluation consisted of capital cost, actual operational cost, and projected operational cost summaries.

NORTH LITTLE ROCK FACILITY

Description

General--

The North Little Rock facility, formally called the North Shore Energy Facility, is located in an industrial area of North Little Rock, Arkansas (see Figure 14). During the time of this evaluation, the city was collecting an average of 63.5 Mg (70 tons) of solid waste per day with eight rear-loading packing trucks. The city collects the residential refuse from some 20,000 homes and the industrial refuse from 20 percent of the approximate 2,000 commercial and manufacturing firms. A private hauler, with a 23m^3 (30-yd^3) front-loading truck and a container system, collects the other 80 percent of the industrial waste. Only a small portion of this industrial waste is taken to the energy facility. The remainder goes to the sanitary landfill. The estimated 1978 waste throughput of the North Little Rock Plant was 13,721 Mg (15,125 tons). Four Consumat Model CS-1200 modular incinerators integrated with heat recovery equipment burn the waste and produce steam which is delivered under contract to the nearby Koppers Corporation, a manufacturer of creosote-treated wood products. The contract calls for an average 6804 kg/hr (15,000 lb/hr) of steam at 150 psi to be delivered 24 hours per day, 5 days per week.

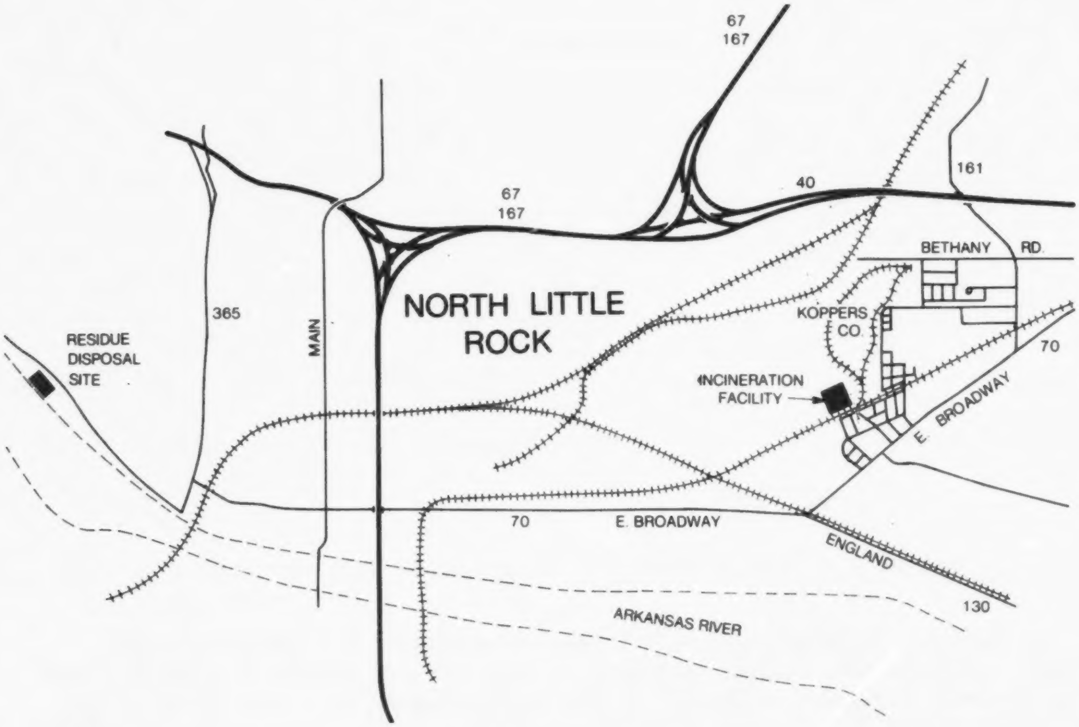

67
167
161
40
67
167
BETHANY RD.
365
MAIN
NORTH LITTLE ROCK
KOPPERS CO.
RESIDUE DISPOSAL SITE
70
INCINERATION FACILITY
E. BROADWAY
70
E. BROADWAY
ENGLAND
130
ARKANSAS RIVER

Figure 14. Vicinity map of North Little Rock facility.

The plant lies on a relatively flat 2-acre site adjacent to the Koppers' plant and a railroad line. Koppers leases the site to the city for a nominal yearly sum. A grade crossing, which is an extension of a street, provides access to the plant.

There are two structures on the site: a main building with a wing on each side, one facing east and the other west, and an administration building southwest of the main building and nearer to the plant access (see Figure 15). The traffic routing to and through the main building starts at the grade crossing, proceeds to the truck scale about 11m (35 ft) north of the administration building, passes the west wing, continues through the centrally located north door for the refuse deposit, and concludes with the exit through the opposite south door to the departure lane. Although the incoming and outgoing lanes cross, the truck traffic proceeds smoothly because of the clear visibility in the area and the usually sufficient time intervals between truck deliveries and departures.

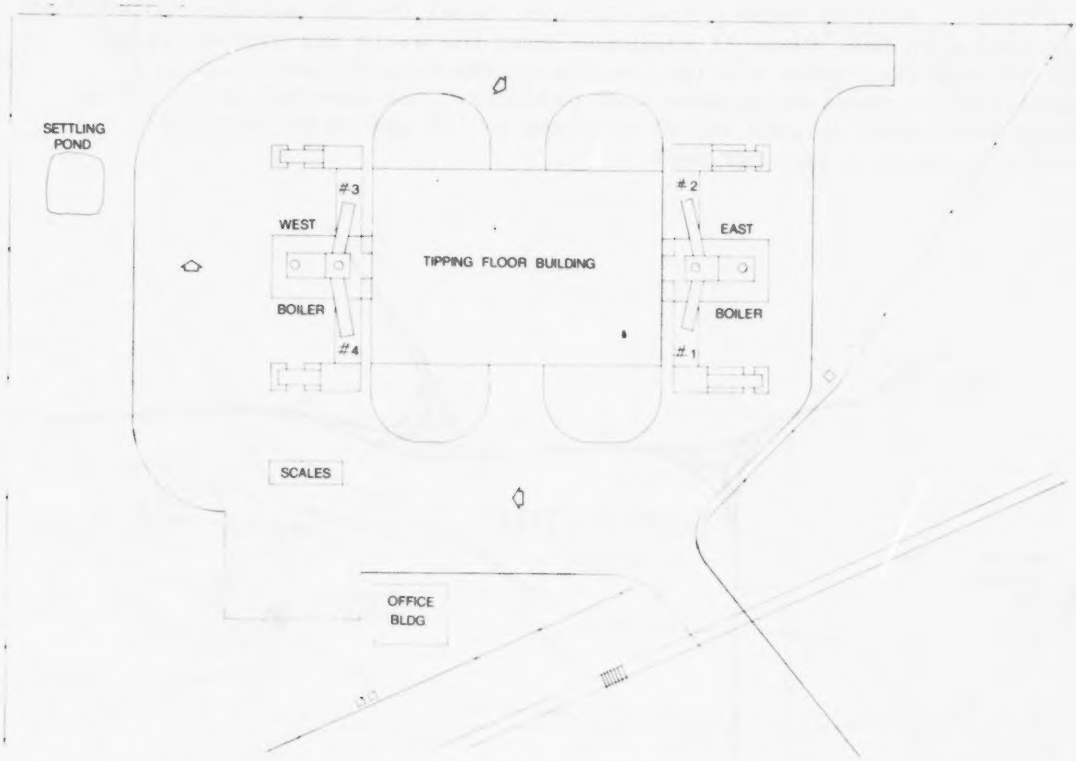


Figure 15. Plant layout of North Little Rock facility.

In addition to management and locker room areas, the administration building includes the digital readout for the truck scale and a 24-hour chart recorder and a digital integrator of the steam production. The truck scale is a Toledo Model 8030 with a Honeywell recorder. With each truck identified by a prominently displayed number, a secretary daily records the following information: arrival time, identification number, gross weight, tare weight, and net weight of each truck, and the totals for the number of trucks and their weights.

The central part of the main building is the tipping floor. Each of the two wings contains an identical waste-to-heat energy module. Each module consists of two identical incinerator systems with a common heat recovery system.

Although integrated into a single building complex, both the central tipping floor building and each of the two incinerator-heat recovery wings are separately enclosed by prefabricated steel walls with integral roofing for each enclosure. While each of the wing walls rests on a concrete floor 2.13m (7 ft) below the tipping floor, the tipping area walls are supported by a 1.07m (3 1/2-ft)-high by 15.24-cm (6-in.)-thick wall (wainscotting). At the entrance to each wing, a loading platform aligned level with the tipping floor extends into the waste-to-heat energy module area.

Tipping Floor--

Constructed of 15.24-cm (6-in.)-thick concrete, the tipping floor is 36.58m × 24.38m (120 × 80 ft). The floor areas immediately in front of the two loading platforms have a specified 34.5-Pa (5000-psi), 28-day compressive strength for additional wear. The wainscotting, which also protects the walls from vehicle contact, is continuous except for the entrances for the trucks and to the loading platforms. Each of the truck doors is an overhead type 5.5m × 5.5m (18 × 18 ft). Within the tipping floor area, the minimum clearances are 5.5m (18 ft) near the walls and 6.10m (20 ft) under steam lines. The tipping floor area was designed so that a skid-steer loader could push the truck-deposited refuse into each of the four corners for temporary storage and then could push the piled refuse alternately to each of the two loading platforms.

Waste-to-Energy Module--

As mentioned, the waste-to-energy modules in the two wings are identical. Except for the configuration to integrate with the common heat recovery system, the two incinerator systems in each module are also identical. Figure 16 presents a 3-dimensional drawing of the basic module. The following subsections describe the module components generally in the order of the waste-to-energy flow.

Waste loading System--This system consists of a hopper, a ram, a loading display panel, and a control panel. The hopper is 1.8m (6 ft) long, 1.2m (4 ft) wide, and 1m (3 ft) deep and is covered by a hinged door that aligns with the loading platform. The hinged door is activated by the operator of the skid-steer loader when the charge light comes on. A hydraulic cylinder opens and closes the door. The switch for the cylinder activation is at the end of the electrical line that extends from the main control panel in the module area to the tipping area ceiling and then is suspended to a convenient height for the operator on the tractor over the loading platform.

Hydraulically operated by one cylinder and a cable system, the refuse injection ram is a double-acting reciprocating unit that alternately pushes the refuse in the hopper into the primary combustion chamber on each side of

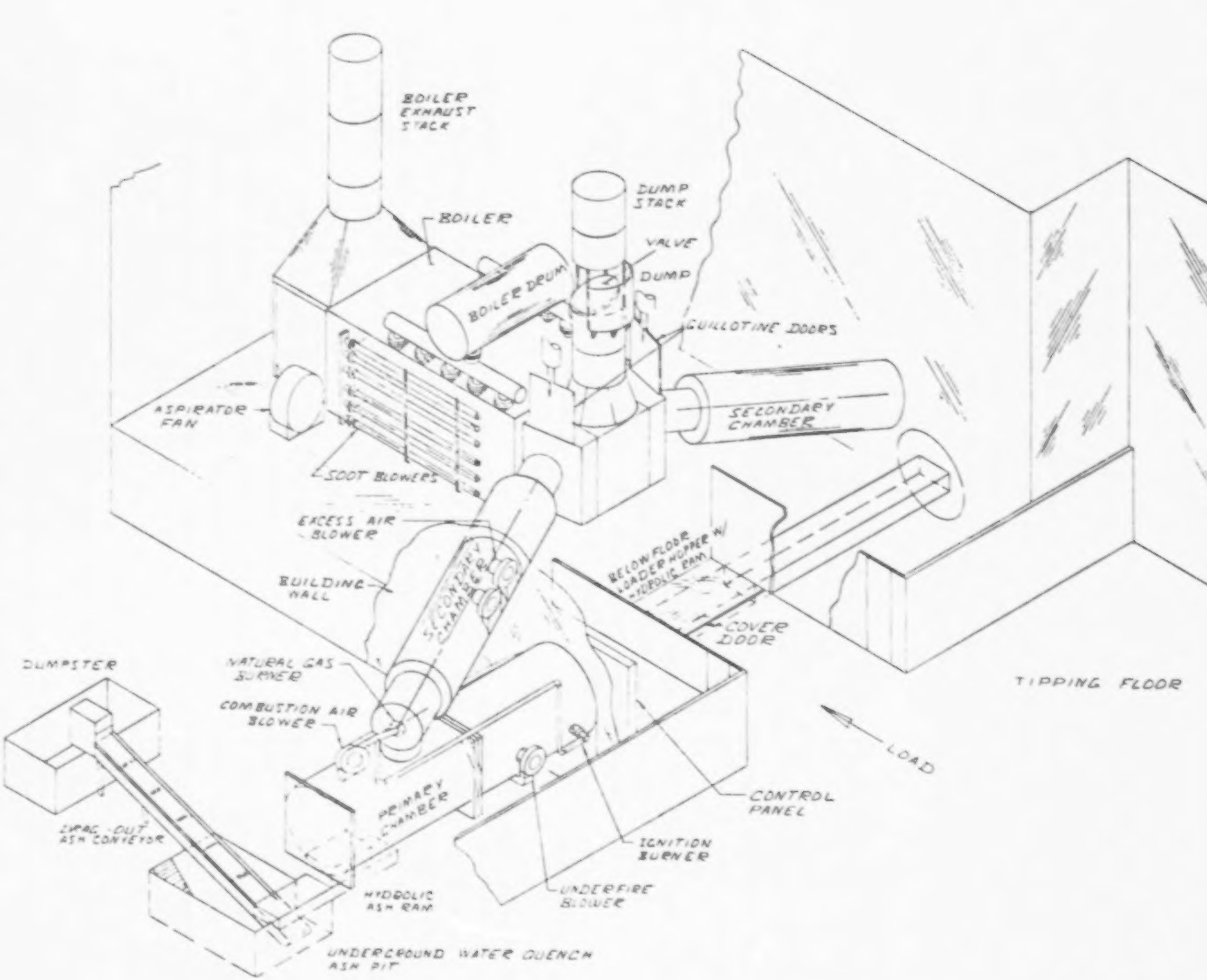

BOILER EXHAUST STACK
BOILER
BOILER DRUM
DUMP STACK
VALVE
DUMP
GUILLOTINE DOORS
SECONDARY CHAMBER
ASPIRATOR FAN
SOOT BLOWERS
EXCESS AIR BLOWER
BUILDING WALL
SECONDARY CHAMBER
BELOW FLOOR LOADER HOPPER W/ HYDROLIC RAM
COVER DOOR
TIPPING FLOOR
LOAD
CONTROL PANEL
DUMPSTER
NATURAL GAS BURNER
COMBUSTION AIR BLOWER
PRIMARY CHAMBER
IGNITION BURNER
UNDERFIRE BLOWER
DRAG-OUT ASH CONVEYOR
HYDROLIC ASH RAM
UNDERGROUND WATER QUENCH ASH PIT

Figure 16. Three-dimensional drawing of incineration-heat recovery module in North Little Rock facility.

the hopper. A preset timer controls the ram-loading cycle. The fire door on each of the primary chambers is a 1m × 1.2m (3- × 4-ft)-guillotine type that is raised by two hydraulic cylinders. All hydraulic cylinders are powered by a Deyhco Model 130 F, 11-kilowatt (15-hp) motor and hydraulic pump system.

The lighting of lamps and messages on the loading display panel informs the loading operator of the following: (1) when to load the hopper, (2) which of the two primary chambers to load next, and (3) how much refuse to put into the hopper. The amount of the load (heavy, medium, or light) is a function of the temperature in the primary chamber. Figure 17 shows the panel.

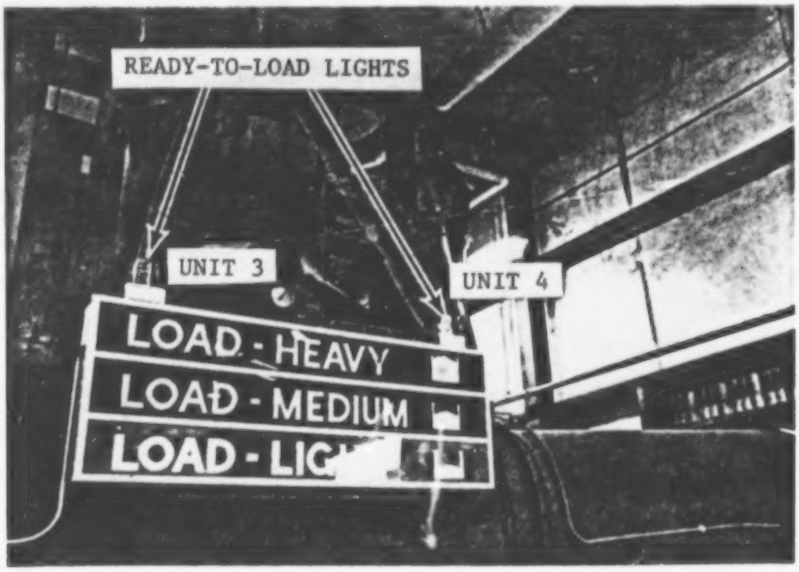


Figure 17. Display panel for refuse loading instructions in North Little Rock facility.

Primary chamber--Incorporating a 3-tiered hearth, the primary chamber (see Figure 18) is a 7.3m (24-ft)-long, 2.7m (9-ft)-diameter cylinder. It is constucted in two sections of 6.5-mm (1/4-in.) rolled steel and stands on a steel leg framework in a large concrete pit outside the building. The transition section from the hopper to the combustion area passes through the building wall.

Both the transition section and the upper half of the chamber are lined with 12.7-cm (5-in.)-thick Plibrico Plicant Steel Mix castable refractory which is designed for operating temperatures up to 1454° C (2650° F). A 5.08-cm (2-in.)-thick block insulation lies between the refractory and the steel shell. Stainless steel anchors secure the refractory to the shell. Each of the three tiers forming the hearth is flat and is lined with refractory brick. This brick, which is an A. P. Green Type MC-22 and is rated as a high duty rotary kiln block, also covers the lower half of the primary chamber.

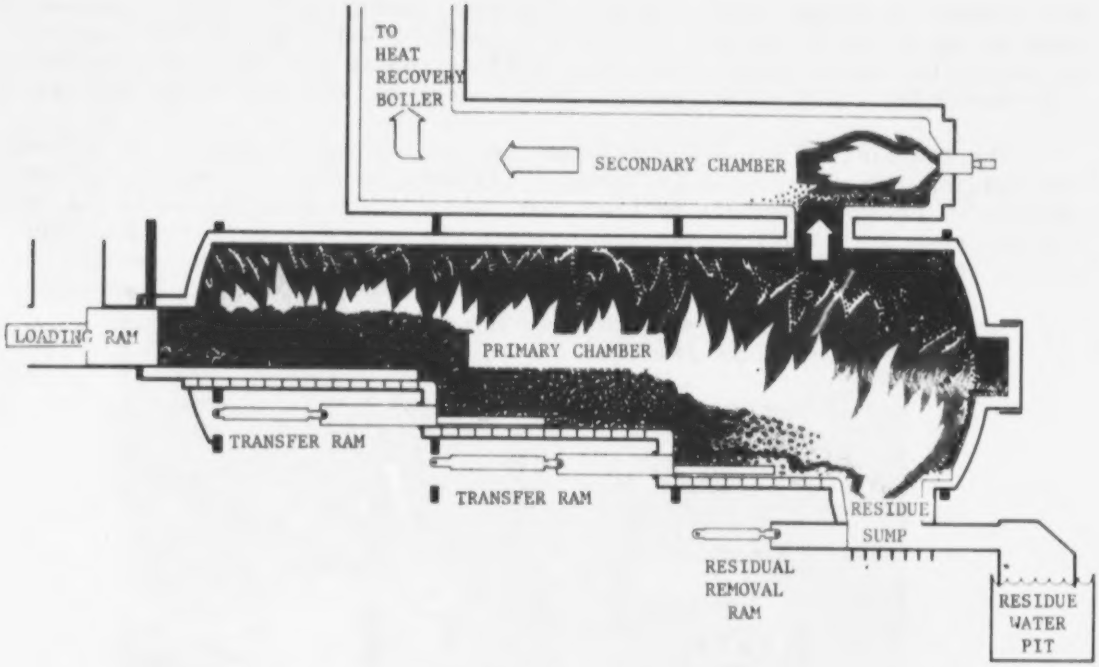


Figure 18. Cross section of incinerator module in North Little Rock facility.

The first tier at the chamber front aligns with the bottom of the hopper. The second and the third tier each drop several feet. The third tier ends at the entrance to a dry ash sump below the primary chamber end. On both the second and the third tiers, a ram pushes the ash forward. Stationary water-jacketed tubes in each ram both guide the ram movement and supply underfire air to the chamber. Each ram face is water-jacketed, is half the height of the drop, and extends the width of the hearth. Actuated automatically by a timer in the central control panel, each ram is hydraulically driven by a cylinder that is powered by the motor-hydraulic pump assembly for the waste loading system. The air tubes in the two rams are individually coupled to flexible tubes extending from a combustion air plenum beneath the front of the chamber. A Dayton Model 4C330 3.7-kilowatt (5-hp) blower supplies air to the plenum.

The underfire air is automatically regulated to keep the primary chamber temperature at the designed level and to permit such mechanical operations as ash removal. To complement the combustion air regulation for the temperature control, two nozzles for spraying water mist into the chamber were installed at the one-third and two-thirds distances along the chamber.

Two burners near the front of the chamber, one on each side at the mid height and both pointed down slightly, fire the chamber to the 316° C (600° F) start-up temperature. These burners, North American Model 6427-3 dual-fuel units, automatically shut off at 316° C (600° F). A high pressure fan, a

North American Model 2316-26-1-5 unit, supplies air for the burners. After the start-up, the fan remains on to protect the burners from the operating temperatures (see Figure 19).

As the combustion gases leave the top of the primary chamber to enter the bottom of the secondary chamber above, they pass through a short duct called the throat. The throat is near the center of the primary chamber and the front of the secondary chamber. With a 5-cm (2-in.)-thick block insulation next to the steel shell, the throat is lined with a 13-cm (5-in.)-thick Plibrico Plicart K-L Mix castable refractory. The throat has a ring of holes through which preheated air from the secondary chamber plenum is tangentially mixed with the combustion gases exiting the primary chamber.

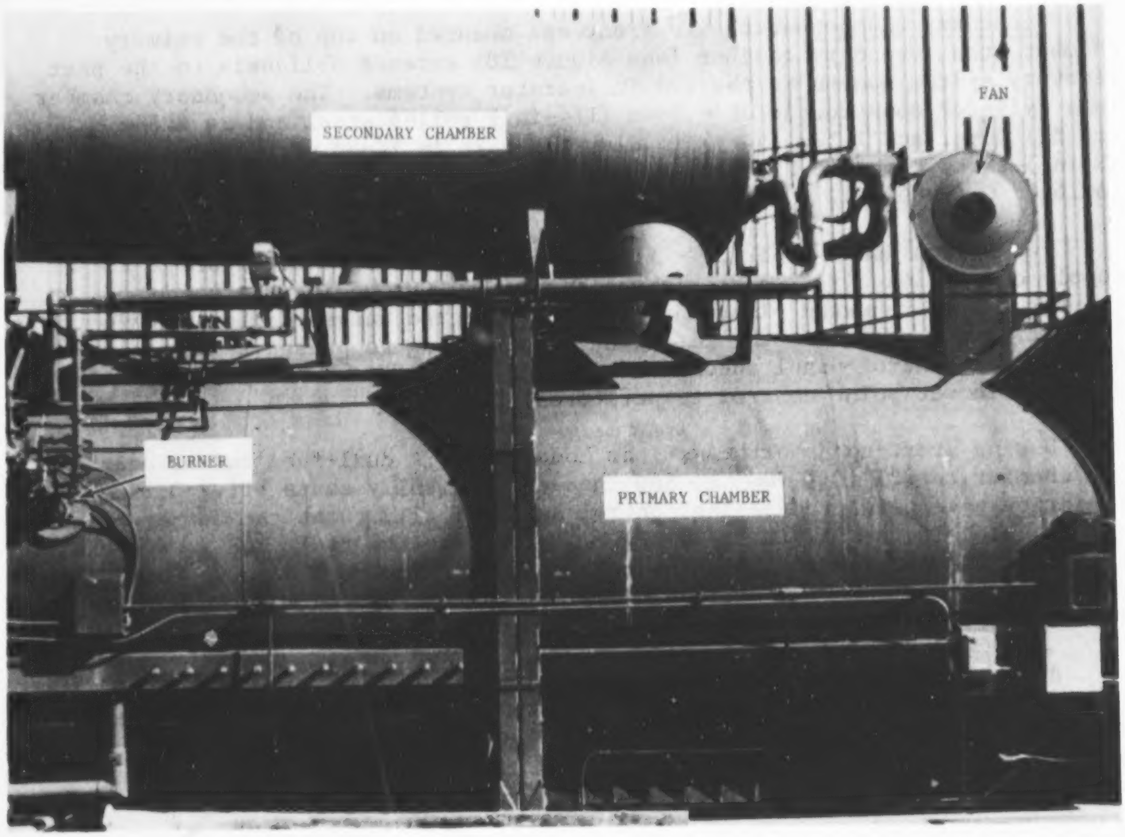


Figure 19. Side view of west-end combustion chambers with fan and burner for primary chamber indicated.

The cooling system for the primary chamber includes the water jacket for the dry ash sump (discussed later) as well as those for the ram tubes and faces. In addition to preventing the distortion and deterioration of the foregoing water-jacketed components, the cooled surfaces help restrict excessive slag formations by lowering temperatures of the refuse in the primary chamber. The water used in the cooling process is routed to the boiler deaerator tank which subsequently supplies water to the boiler. A water softener system treats all the water ultimately fed to the boiler. Besides the water jackets, the cooling system consists of a temperature regulating valve, a pressure relief valve, manual valves, and interconnecting water lines.

The entire rear of the primary chamber swings completely open on a counterweighted hinge. This unrestricted access permits inspection and repair of the refractory, the rams, and the underfire air tubes and removal of slag and residual ash during the weekend shutdown. A 0.6m × 1m (2- × 3-ft) door in the center of the rear structure provides the means for periodically inspecting the residue accumulations and slag formations during operation.

Secondary chamber--With its front end mounted on top of the primary chamber, the secondary chamber (see Figure 18) extends obliquely to the heat recovery system common to the two incinerator systems. The secondary chamber is a cylinder constructed of 6.5-mm (1/4-in.) rolled steel and is 4.88m (16 ft) long, and 1.52m (5 ft) in diameter. It is lined with 13-cm (5-in.)-thick Plibrico Plicant K-L Mix castable refractory that is rated up to 1650° C (3000° F).

Two Dayton Model 2C652 3.7-kilowatt (5-hp) blowers (see Figure 20) supply combustion air to a double-walled plenum surrounding the secondary chamber. The preheated plenum air is then injected tangentially into the chamber through holes in the refractory. According to preset temperatures, the central control panel automatically modulates dampers on the fan intakes to maintain set point control temperatures.

During start-up a North American Model 6422-7A dual-fuel burner heats the chamber to 927° C (1700° F) and then automatically shuts off. During operation a temperature-sensing control automatically turns the burner on and off to maintain the 927° C (1700° F). A blower at the front and toward the bottom of the chamber supplies the combustion air for the burner. This blower is the same North American Model 2316-26-15 that serves the burners for the primary chamber.

As the hot gases exit the secondary chamber, they pass through a refractory-lined breech that directs the gases to a refractory-lined tee section at the base of the dump stack (see Figure 21). A hydraulically operated guillotine door at the breech entrance into the stack base permits shutting down one incinerator system while operating the other.

Dump stack--The dump stack provides the means for either discharging the hot flue gases to atmosphere or directing them to the heat recovery boiler. Constructed of stainless steel, the dump stack is 9m (30 ft) high and 1m (3 ft) in diameter. A structural platform, consisting of prefabricated sections bolted together, supports both the stack and the heat recovery sections. It also provides inspection and maintenance access to the heat recovery equipment.

The stack base is a large refractory-lined box. A refractory-lined cap (see Figure 22) at the entrance to the stack proper controls the flue gas flow, i.e., either vertically up the dump stack or horizontally through the

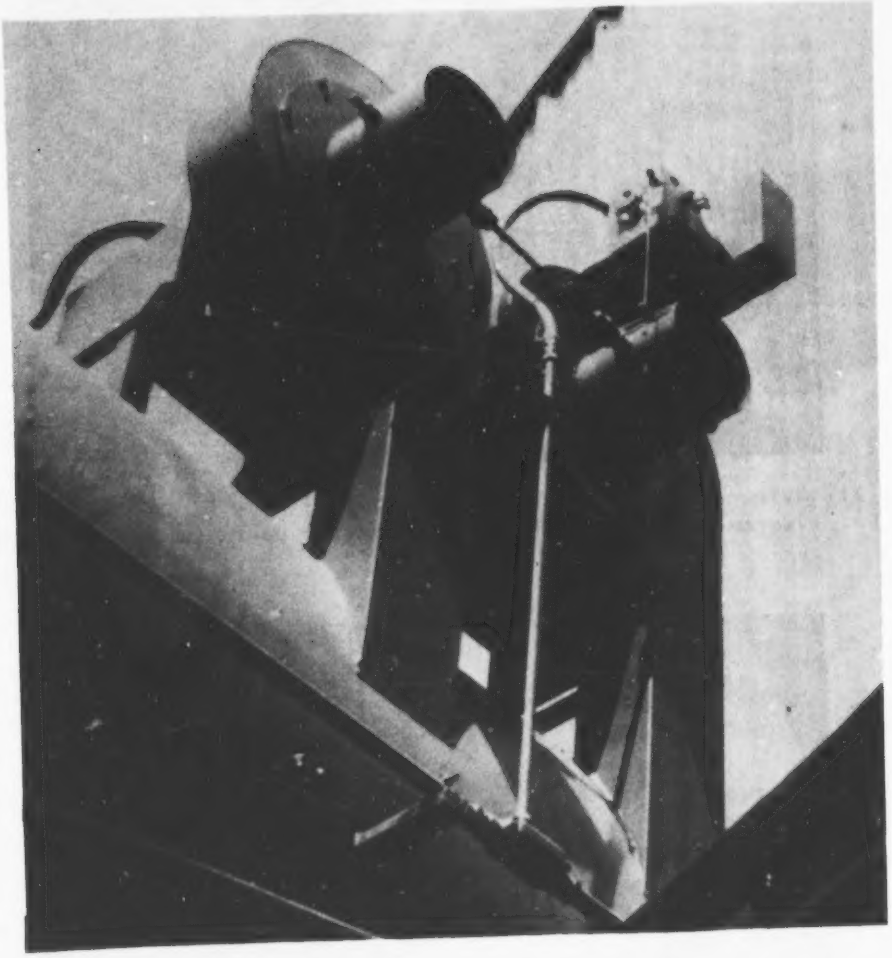


Figure 20. Two combustion air fans for each secondary chamber.

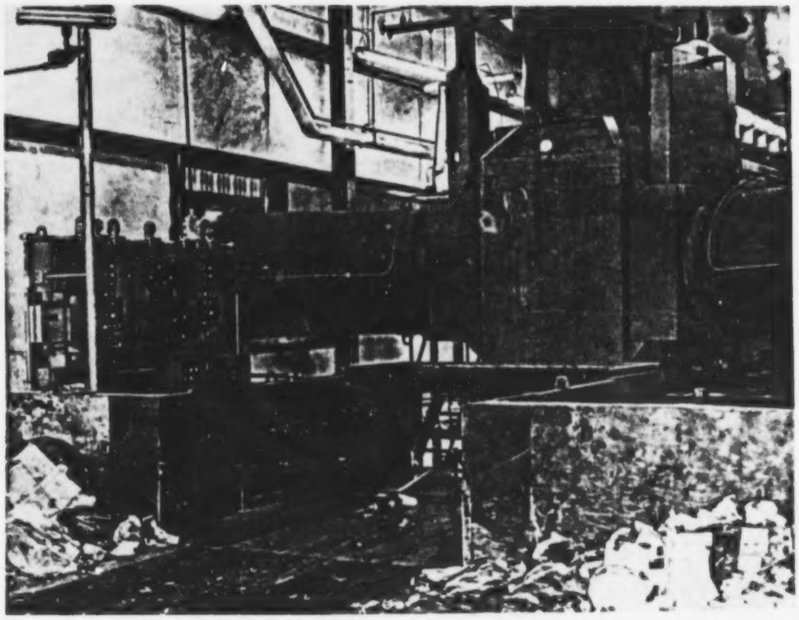


Figure 21. View showing tee section at base of dump stack, connecting secondary chamber breeches, control panel, and loading platform.

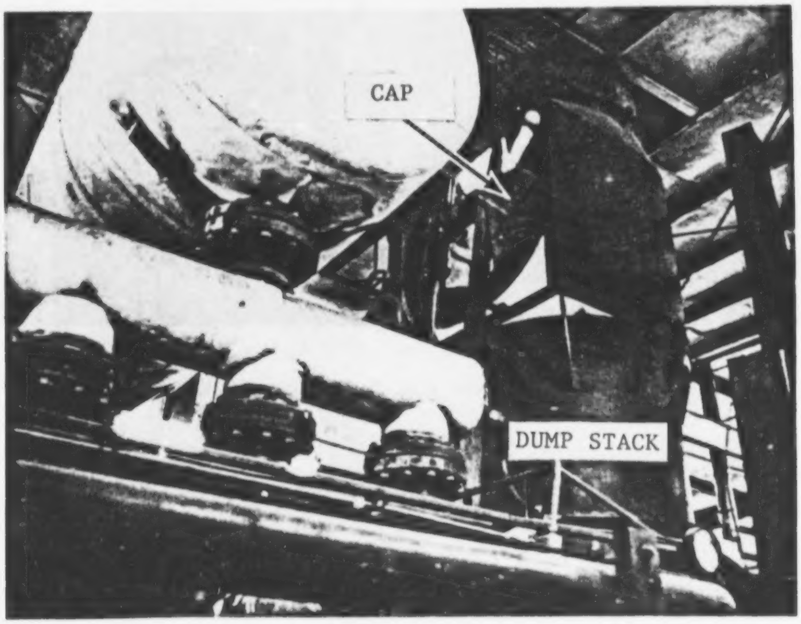


Figure 22. View of dump stack beside steam drum with pneumatically closed dump cap indicated.

heat exchanger. When there is a steam demand, the cap is pneumatically closed; when there is no steam demand, the cap is held open by a counterweight. A large door on a side of the stack base provides inspection and maintenance access to the heat recovery sections.

Heat recovery system--The flue gases directed into the heat recovery system pass through a heat exchanger consisting of five banks of vertical water tubes. In the first bank the tubes have no fins, in the second and third banks they have large fins, and in the fourth and fifth banks they have small fins. Each bank is a module that can be individually removed for maintenance and repair. A soot blower (Figure 23) directs compressed air over each tube bank in a top-to-bottom cycle. Soot blowing is automatically controlled by a timer with time intervals ranging from 4 to 6 hours. Approximately 35 minutes is required for one soot-blowing operation. An Ingersol Rand Model 71T2-T30117M 7.5-kilowatt (10-hp) air compressor supplies the blower with air at 220 psig.

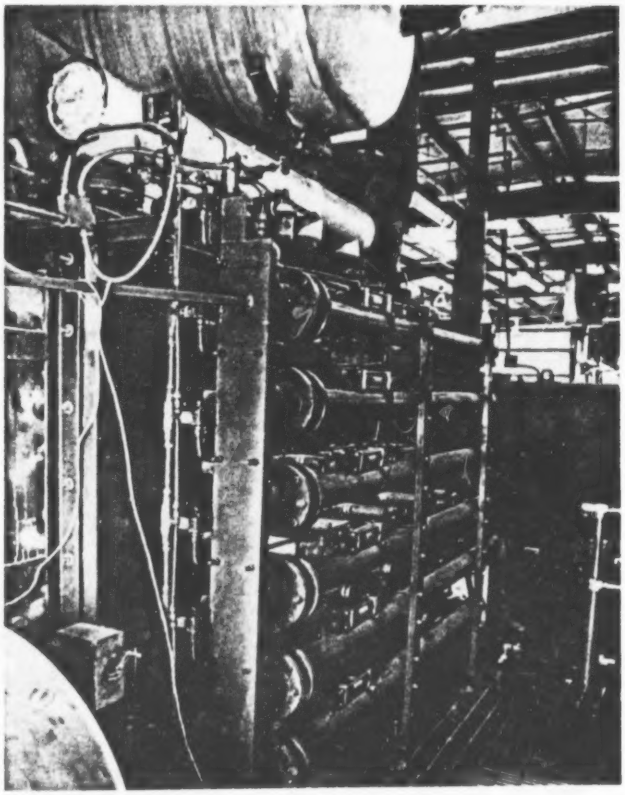


Figure 23. Boiler tube soot-blowing assembly.

The feed water to the heat exchanger tubes is delivered by two Burks Model E23SP pumps each powered by a 3.7-kilowatt (5-hp) motor. An identical third pump serves as a backup. At the outset, the water supply from the city is softened by a Hydro-Max Model 5M 1201 1/2 unit. The softened water is then metered into a Cochrane 2.07- × 10^5-Pa (30-psi) deaerater tank where two separate small mixing tanks add water-treatment chemicals. As mentioned above, the feedwater is partially preheated in the cooling process from the water-jacketed ram faces and air tubes in the primary chamber and from the water-jacketed dry ash sump. The feedwater is further heated and deaerated by injecting steam into it.

The steam generated in the boiler flows to a steam separator drum which is mounted above and across the boiler enclosure. With 2.1m (7-ft)-long and 1.2m (4-ft)-diameter dimensions, the steam drum has such standard and safety equipment as pump-on and pump-off controls, high and low water-level alarms, a low water cutoff, dual pressure relief valves, and blowdown drains (see Figure 24).

At the east end of the plant, a York-Shippley Model 5PH-300-N2-FAH-6781 dual-fired boiler serves as a backup for the heat recovery system. The boiler can produce 4695 kg/hr (10,350 lb/hr) of steam at 1.03 × 10^6 Pa (150 psi). A fourth Burks Model E23SP pump supplies the feedwater to this boiler.

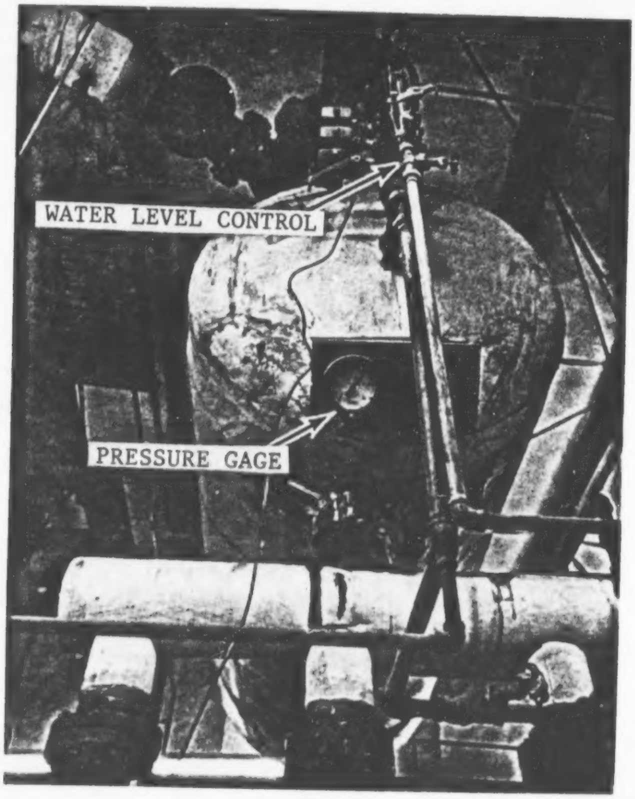


Figure 24. View of steam drum with water level control and pressure gage indicated.

As the flue gases exit the boiler, they flow into the exhaust system consisting of a stack and an aspirator section in the stack base. Beside the stack base, a 14.9-kilowatt (20-hp) aspirator fan blows high velocity air into the boiler outlet section. As the air rises into the stack proper, it creates sufficient draft to aspirate the flue gases through the boiler. Constructed of stainless steel, the stack is 6.1m (20 ft) high and 1m (3 ft) in diameter.

Residue removal system--The transfer rams push the residue toward the rear of the primary chamber where it falls through the hearth floor exit to the water-jacketed dry ash sump. After several refuse-loading cycles, another hydraulically driven ram pushes the dry residue deposit into a water sump below and outside the chamber enclosure. As the dry residue falls toward the water sump, nozzles spray water mist on it to prevent its producing steam when it enters the water. In addition to preventing a steam blowback through the hearth residue bed (that would agitate particulates into the combustion gases), a pipe connecting the water sump to the chamber equalizes the pressure and further minimizes particulate agitation.

After the residue has remained in the water sump for about 15 minutes, a drag chain conveyor transports the residue to the top of an incline where the residue is dumped into a drop box container (see Figures 25 and 26). A Delta Power Model C21 hydraulic pump with a 2.2-kilowatt (3-hp) motor powers the conveyor and the container-loading spill chute. A load-lugging lifter mounted on an International truck periodically replaces the filled container with an empty one.

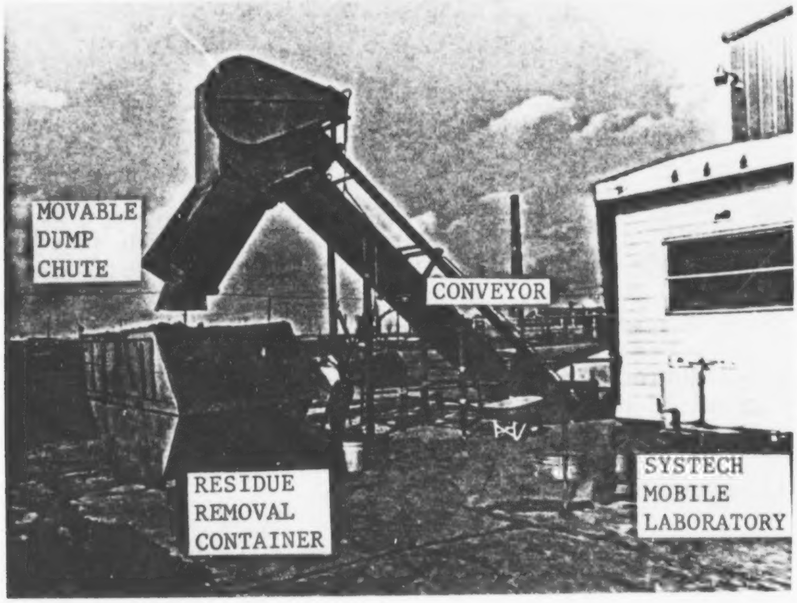


Figure 25. View of automatic residue removal system with conveyor, movable dump chute, and residue removal container indicated.

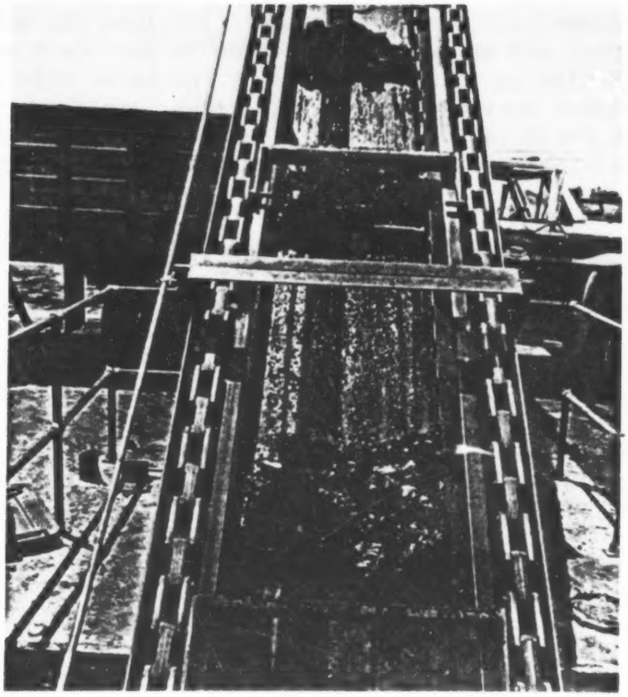


Figure 26. Residue removal conveyor.

Operation

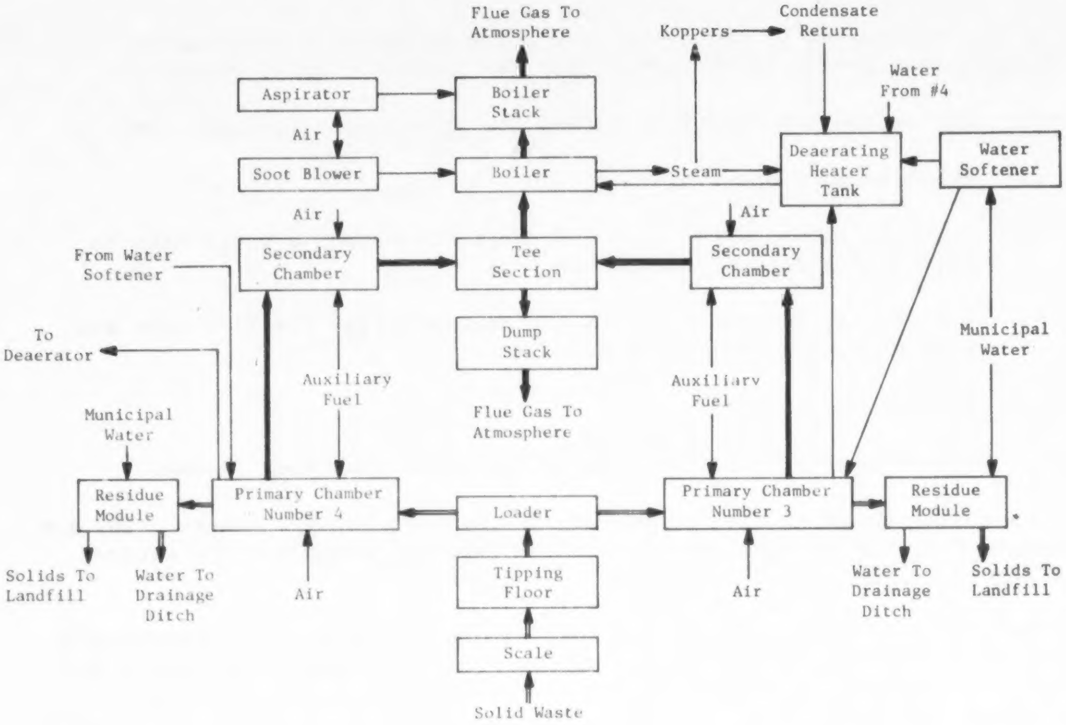
Figure 27 shows a flow diagram of the incineration-heat recovery processes.

Refuse Loading--

The operator of the skid-steer tractor on the tipping floor has the two-fold task of pushing the truck-deposited refuse into each of the four floor corners for temporary storage and of pushing the piled waste along the loading platform to the hopper in both the east and the west waste-to-energy modules (see Figure 28).

When the lighting of the loading display panel indicates the need for refuse, the operator performs the following:

1. Gathering a light, medium, or heavy load as directed by the illuminated LOAD sign.
2. Turning on the ceiling-suspended switch to actuate the opening of the hopper door.
3. Dumping the collected refuse into the hopper.
4. Turning off the switch to actuate the closing of the hopper door.



Flue Gas To Atmosphere
Koppers
Condensate Return
Water From #4
Aspirator
Boiler Stack
Air
Soot Blower
Boiler
Steam
Deaerating Heater Tank
Water Softener
Air
Air
From Water Softener
Secondary Chamber
Tee Section
Secondary Chamber
To Deaerator
Dump Stack
Municipal Water
Auxiliary Fuel
Flue Gas To Atmosphere
Auxiliary Fuel
Municipal Water
Residue Module
Primary Chamber Number 4
Loader
Primary Chamber Number 3
Residue Module
Solids To Landfill
Water To Drainage Ditch
Air
Tipping Floor
Air
Water To Drainage Ditch
Solids To Landfill
Scale
Solid Waste

Figure 27. Flow diagram of incineration-heat recovery processes in North Little Rock facility.

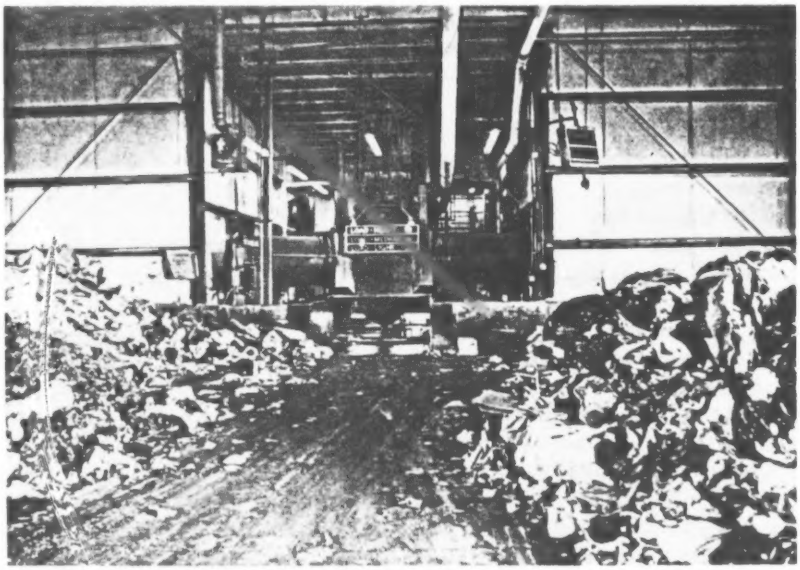


Figure 28. West-end view of tipping floor with loading display panel in background.

At the completion of the fourth step, the following operations are performed automatically in the hopper and the primary chamber areas:

1. The mechanical functions within the primary chamber shut off.
2. The fire door opens.
3. A nozzle close to the fire door entrance sprays a water mist to prevent flashing in the hopper.
4. The ram in the hopper pushes the refuse beyond the fire door and then withdraws from the door.
5. The fire door closes.
6. The mechanical functions within the primary chamber resume.

The entire cycle of the ram movement requires about 1/2 minute. The ram is then reactivated to push refuse into the opposite chamber. The entire cycle for refuse injection is automatically timed.

The load-size indicators on the loading display panel are automatically lighted according to the correlation of the primary chamber temperature with preset lower and upper limits. The three load sizes, namely, LOAD HEAVY, LOAD MEDIUM, and LOAD LIGHT, refer only to the quantity, that is, cubic yards of the refuse. Therefore, there is no need to vary the quality of the refuse gathered for any one of the three load sizes indicated. When the chamber temperature is above the high set point, the LOAD HEAVY frame, which represents the largest load, illuminates so that the next load will lower the temperature below the maximum level. When the chamber temperature is at the desired operating level, the LOAD MEDIUM frame, which represents the intermediate load, illuminates so that the next load will maintain the current temperature. When the chamber temperature is below the low set point, the LOAD LIGHT frame, which represents the smallest load, illuminates so that the next load will raise the temperature above the minimum level.

Controlled Air Incineration--

The controlled air incineration process is performed by regulating the interacting combustion variables in the primary and secondary chambers.

Several factors affect the combustion gas production in the primary chamber. The gases developed in this chamber are produced primarily by the interaction of the air with the oxidized and volatilized products from the waste. The amount of gas produced varies substantially with changes in the temperature and in the quantity and type of the waste being burned. To make the gas production as uniform as possible, the airflow controls in the two chambers are closely correlated to restrict gas and particulate velocities and to complete the combustion of large particulates. When either the hopper ram or the hearth rams are cycling, the combustion air blower in the primary chamber is shut off as a cycle begins and remains off until after the cycle completion.

As in the primary chamber, the combustion air and the auxiliary fuel introduced into the secondary chamber are controlled by a central control system. The air and fuel regulations for the secondary chamber govern the controls for the combustion parameters in the primary chamber.

At incinerator start-up, the burner in the secondary chamber is turned on and the damper on the air supply blower is closed by its air modulation motor so that without the air and its cooling effect the chamber temperature can rise more rapidly. When the temperature approaches the 927° C (1700° F) operating temperature as sensed by a thermocouple, the damper motor progressively opens the damper to the approximate full-open position until 927° C (1700° F) is reached. While the damper is opening, the burner is simultaneously turned down and ultimately off.

Steam Production--

In order to recover a high percentage of heat in the flue gases exiting the secondary chamber, the gases are slowly drawn through the heat exchanger by a negative pressure between 350 and 700 Pa (0.05 and 0.10 psi) at the inlet side. While the aspirator fan located adjacent to the boiler exhaust stack produces the negative pressure, the magnitude of the pressure is a function of the aspirator fan inlet damper modulation. A pressure-sensing device, a small null switch (see Figure 29) at the inlet side of the boiler, actuates the aspirator fan inlet damper modulator to maintain the preset pressure (and therefore a constant mass flow) through the system.

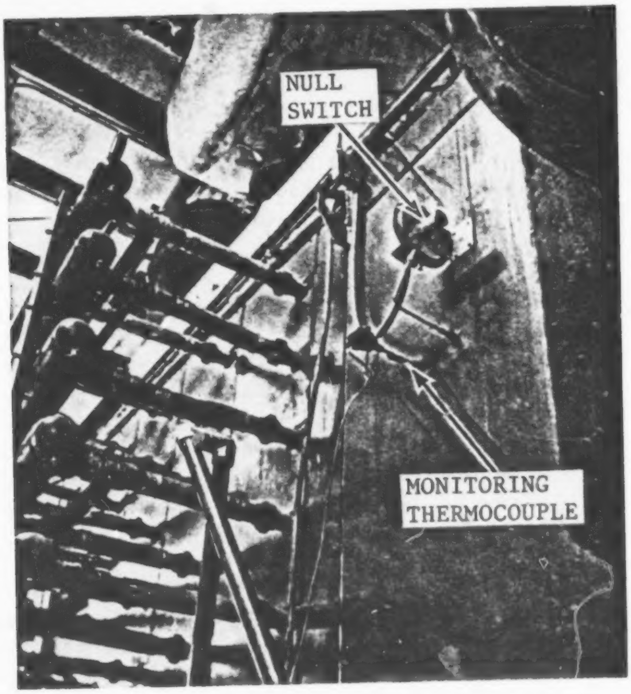


Figure 29. View of tee section and boiler with aspirator control null switch and monitoring thermocouple indicated.

During steam production, the cap at the base of the dump stack is pneumatically closed. Since the cap is normally held open by a counterweight as a fail-safe design, the flue gases are automatically discharged through the dump stack whenever the power fails, the flue gas control system malfunctions, or the water in the steam drum or deaerator tank drops too low.

The steam separator drum is monitored by a pressure control to prevent excessive steam and water pressures. The pressure of the steam available for delivery is a function of the rate at which steam is generated (the recovery rate) and the system pressure. When the recovery rate exceeds the steam demand rate, the rising pressure activates the automatic open-close cycling of the dump stack cap. The flue gas discharged through the dump stack is that amount which will make the recovery rate equal to the steam demand rate. When the steam demand rate exceeds the recovery rate, the cap remains closed and the steam production continues constantly.

Residue Transfer and Removal--

The two rams on the hearth of the primary chamber are cycled to push the residue forward and to break up clinker formations.

The residue removal ram is automatically cycled after a fixed number of loading cycles. The operator periodically opens the small rear door of the primary chamber to visually check the level of the residue bed. If the bed is too deep, he manually cycles the rams. The residue is sprayed with water as it falls into the wet sump. After a delay period the drag chain lifts the residue from the sump and deposits it into the residue removal container.

Site Preparation for Testing

The purpose of the testing was to provide detailed data on the facility performance. Since both wings of the plant are identical and operate under the same conditions, only one set of incinerators and its common steam module were tested. The west end of the plant was chosen.

To monitor the stack emissions, ports for air sampling probes were installed in the boiler stack before and after the aspirator section (see Figures 30 and 31). Since the upper ports were outside the building, a structure to protect the equipment and technicians from the weather was constructed (see Figure 32). Since the facility generated steam 99 percent of the time, no ports were installed on the dump stack. SYSTECH's mobile test laboratory, which housed air emission monitors and recorders, chemicals, other test equipment (see Figure 33), and test records, was parked alongside the building.

The system's energy recovery capability was monitored by installing various meters, timers, and thermocouples throughout the system. Auxiliary fuel was monitored by a rotory gas meter on the natural gas line, and water usage (for calculation of steam production) was monitored by a water meter on the condensate return line and by the existing meter and thermometer in the

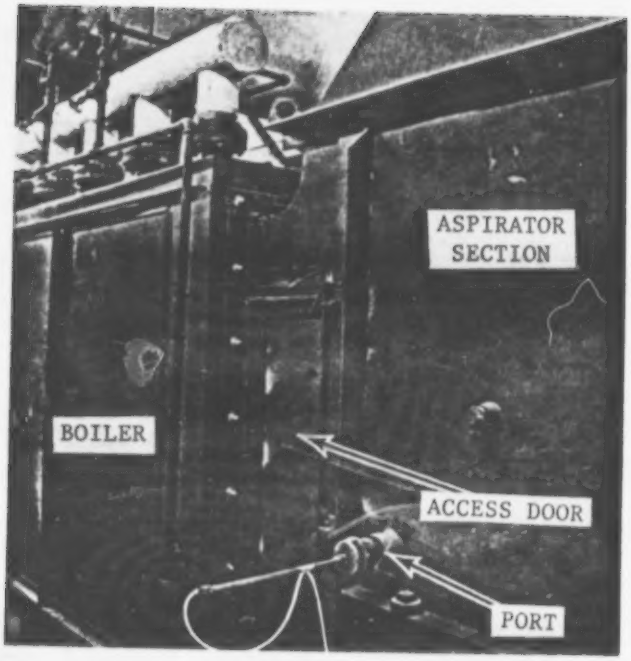

ASPIRATOR SECTION
BOILER
ACCESS DOOR
PORT

Figure 30. View showing aspirator section at right with access door and exiting gas sampling port indicated.

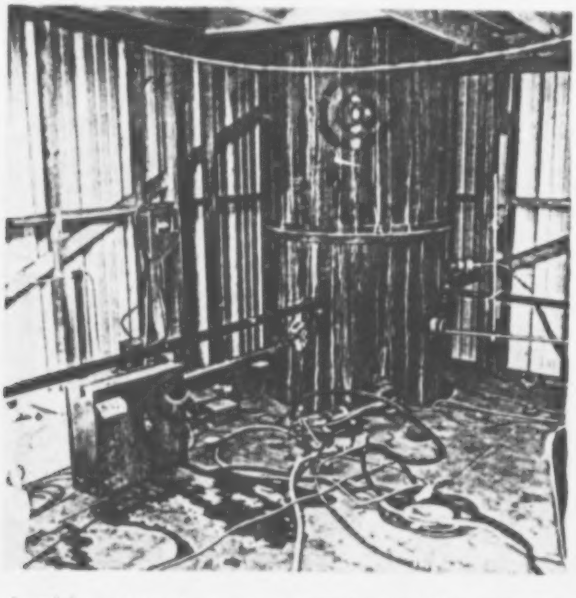


Figure 31. View inside structure to sample boiler stack emissions above the aspirator section. Five sampling ports are visible.

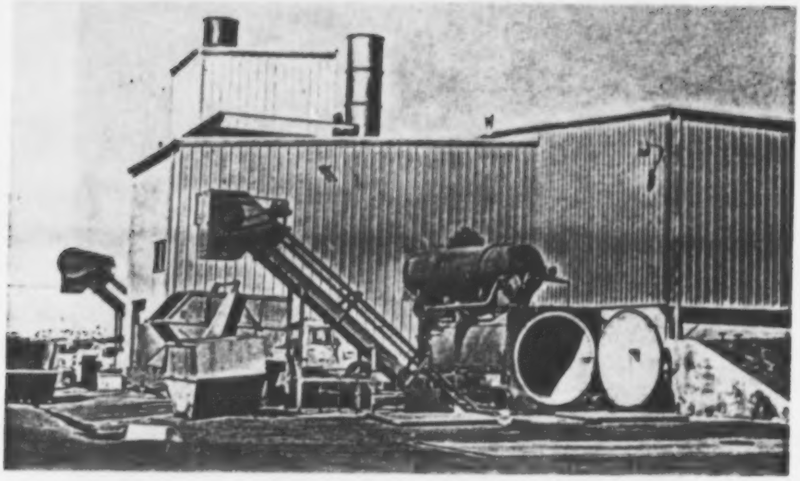


Figure 32. North view of North Little Rock facility showing testing structure on roof and around boiler stack of west-end module.

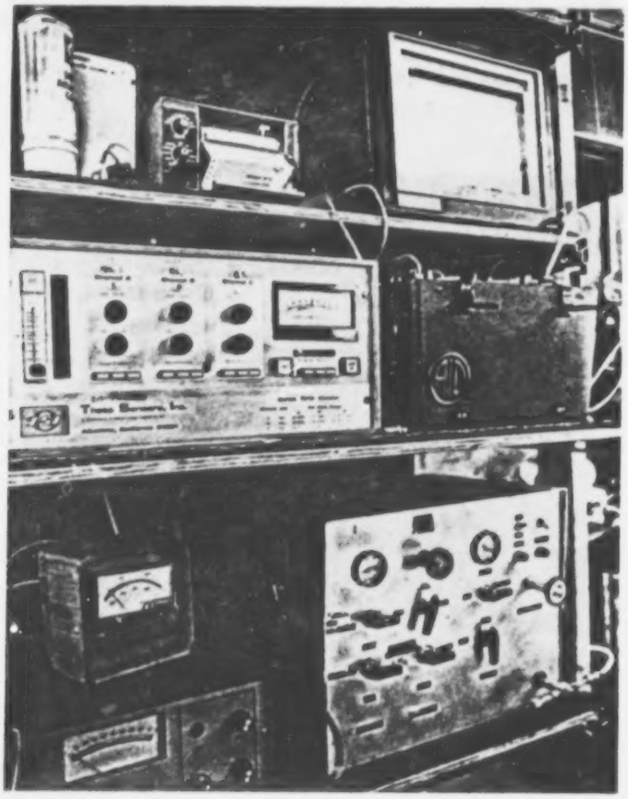


Figure 33. View inside SYSTECH mobile laboratory showing some of the continuous gaseous emission monitoring equipment.

water make-up system. Cycle counters and timers (see Figure 34) were installed in appropriate electrical control boxes to record such events as load cycles and the operating time of the aspirator blower fan and the hydraulic system. A recording ammeter with a continuous recording strip chart was installed on the main power line.

The system outputs were measured by a multipoint strip chart recorder, which received sensor signals from thermocouples installed on the boiler inlet and outlet and existing thermocouples in both of the primary and secondary chambers; a calorimeter installed in the steam line; and existing pressure, temperature, and water-level gauges on the boiler steam drum and deaerator tank. Figure 35 shows the locations of the data collection points on the west end of the facility.

Consumat Systems, Inc., provided a list of the changes made in the equipment during the testing and operational start-up period. They are presented in Appendix A along with changes observed by SYSTECH engineers.

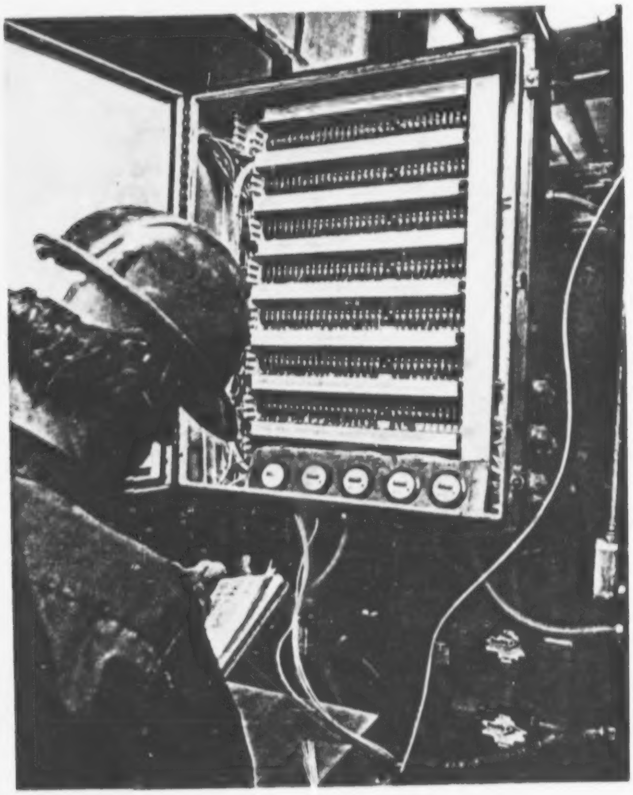
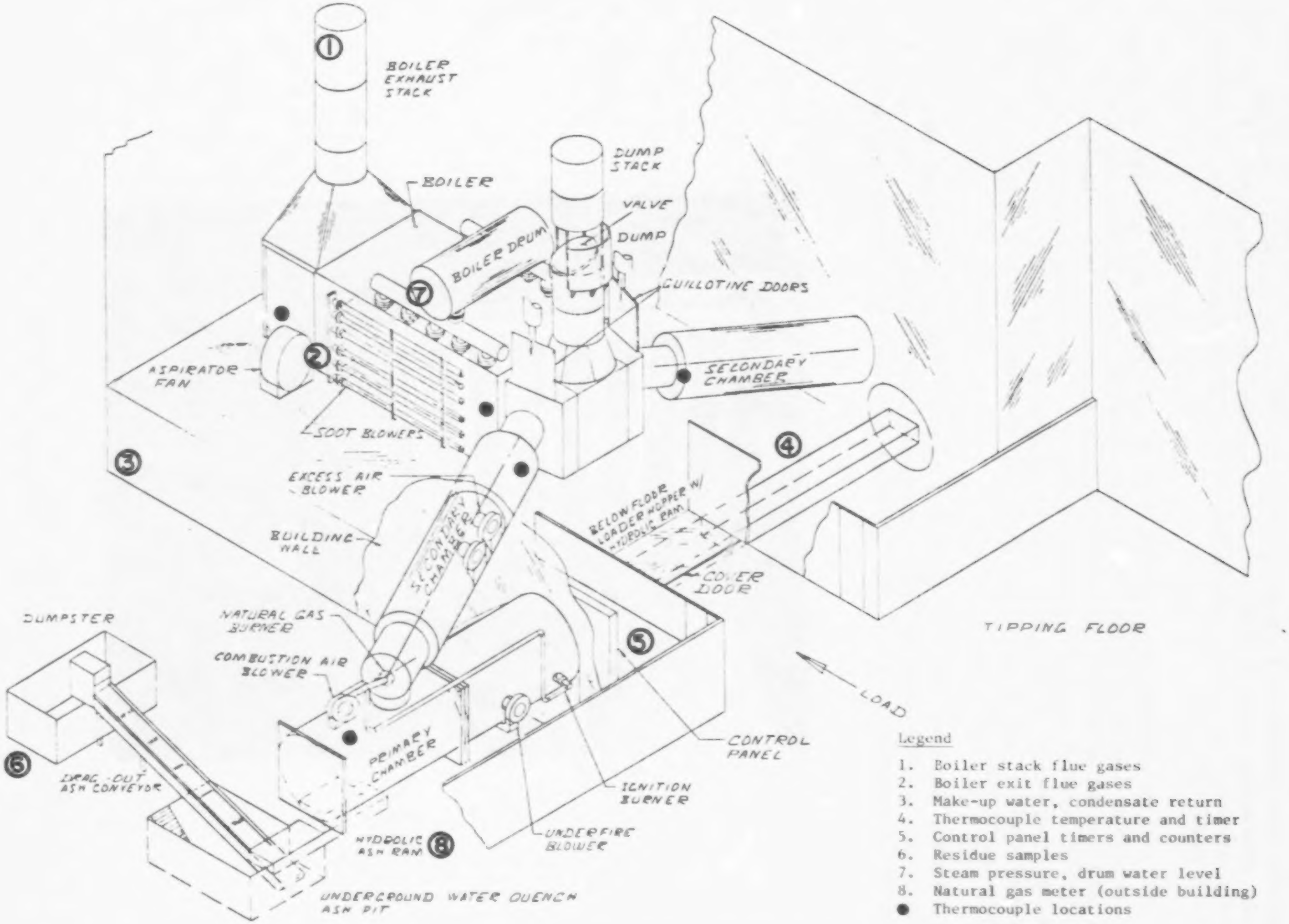


Figure 34. Main electrical panel view showing thermocouple connections and electrical timers.


①
BOILER EXHAUST STACK
BOILER
BOILER DRUM
⑦
DUMP STACK
VALVE
DUMP
GUILLOTINE DOORS
SECONDARY CHAMBER
ASPIRATOR FAN
②
SOOT BLOWERS
③
④
EXCESS AIR BLOWER
BUILDING WALL
SECONDARY CHAMBER
BELOW FLOOR LOADER HOPPER W/ HYDROLIC RAM
COVER DOOR
TIPPING FLOOR
DUMPSTER
NATURAL GAS BURNER
COMBUSTION AIR BLOWER
⑤
LOAD
PRIMARY CHAMBER
CONTROL PANEL
⑥
DRAG-OUT ASH CONVEYOR
IGNITION BURNER
UNDERFIRE BLOWER
HYDROLIC ASH RAM
⑧
UNDERGROUND WATER QUENCH ASH PIT

Legend

1. Boiler stack flue gases
2. Boiler exit flue gases
3. Make-up water, condensate return
4. Thermocouple temperature and timer
5. Control panel timers and counters
6. Residue samples
7. Steam pressure, drum water level
8. Natural gas meter (outside building)

● Thermocouple locations

Figure 35. Locations of data collection points in west-end module of North Little Rock facility.

Refuse Characterizing

Refuse Sampling and Analysis--

Throughout each of the three weekly field tests, the refuse delivered by each truck was sampled and its weight was recorded. Since the plant personnel routinely registered the total and tare weights of each incoming truck, the refuse weight for each truck was simply extracted from the plant records. As each truck dumped its refuse at the west end of the tipping floor, a 55-gal drum was filled with a refuse sample. After the drum was weighed, the sample was dumped at the east end of the tipping floor where it was hand-sorted into 11 refuse categories, and each sort was placed in a separate 30-gal can. When each 30-gal can was filled, the can was weighed and its contents were mixed to ensure a uniform sample. Then a small sample, a tray full, was withdrawn for on-site moisture analysis, and a larger sample was put into a plastic garbage bag to be sent to the SYSTECH laboratory for further processing and laboratory analysis. For the on-site moisture analysis, each of the small samples was immediately weighed, dried overnight at 105° C, and reweighed. The remaining refuse in each of the 30-gal cans was returned to the west end of the tipping floor.

The feed rate was determined by dividing the weight of the refuse delivered by the duration of the test. This procedure worked well for the daily computations during the first two field tests. During the third test, however, the daily computations were complicated by the need to dump incoming refuse on Wednesday and Friday in the same corner as that used on the previous day. Since both corners were clear on early Tuesday and Thursday, the pounds of refuse dumped in three time increments, namely (1) Monday, (2) Tuesday and Wednesday, and (3) Thursday and Friday, were totaled and averaged to yield the pounds per day for each of the three time increments. Then the pounds of refuse for all three time increments were totaled and averaged to yield the pounds per week. In addition, the daily characteristics of the refuse were averaged to minimize variations in the sampling procedures.

Upon arrival at the SYSTECH laboratory, each of the larger samples was dried overnight at 105° C and then milled until the refuse passed through a 5-mm screen. Next a portion of the milled samples was forwarded to a commercial laboratory which conducted a heat content and an ultimate analysis. In the heat content analysis, a bomb calorimeter test yielded values that were compared with the published values.* The heat content of the refuse in each category and consequently the heat content of the weekly refuse supply were calculated from the test data and the published values.

Refuse Characteristics--

For each of the three field tests, Table 4 shows the weekly distribution of the hand-sorted refuse into the 11 refuse categories. Appendix A lists the refuse distribution and moisture content for the daily samples. Except for the March test which had insufficient data, Table 5 shows the weekly moisture content of each of the refuse categories.

---

*A table of the composition and analysis of average municipal solid waste published by Purdue University. This table is presented in Appendix A.

TABLE 4. NORTH LITTLE ROCK WEEKLY REFUSE COMPOSITION FOR MARCH, MAY, AND OCTOBER TESTS

	Test Period					
	March		May		October	
Category	Weekly % by weight	Category weight kg(lb)	Weekly % by weight	Category weight kg(lb)	Weekly % by weight	Category weight kg(lb)
Food waste	8.8	13,104(28,890)	6.7	10,332(22,779)	6.8	13,880(30,600)
Garden	7.2	10,722(23,638)	4.2	6,477(14,279)	3.0	6,1[illegible]3(13,500)
Paper	48.1	71,692(157,914)	49.6	76,489(168,630)	54.1	110,019(242,550)
Plastic	6.1	9,084(20,027)	7.4	11,412(25,159)	8.7	17,758(39,150)
Textiles	3.4	5,063(11,162)	1.5	2,313(5,100)	2.2	4,491(9,900)
Wood	1.4	2,085(4,596)	1.1	1,696(3,740)	1.0	2,041(4,500)
Ferrous	8.3	12,360(27,249)	9.8	15,113(33,318)	8.8	17,962(39,600)
Aluminum	1.1	1,638(3,611)	1.8	2,776(6,120)	3.2	6,532(14,400)
Glass	10.9	16,232(35,785)	11.8	18,197(40.118)	7.6	15,513(34,200)
Inert	1.6	2,383(5,253)	0.4	617(1,360)	0.3	612(1,350)
Fines	3.2	4,765(10,506)	5.7	8,791(19,380)	4.1	8,369(18,450)
Total#	100.1	149,198(328,631)	100.0	154,350(339,980)	99.8	203,483(448,200)

Totals do not equal weighed refuse total due to rounding and averaging.

TABLE 5. NORTH LITTLE ROCK WEEKLY REFUSE MOISTURE CONTENT FOR MAY AND OCTOBER TESTS*

Test period - May

Category	Weekly average moisture* (%)	Weekly total weight kg(lb)	moisture weight kg(lb)	Dry weight kg(lb)
Food waste	54.4	10,332(22,779)	5,621(12,392)	4,711(10,387)
Garden	43.5	6,477(14,279)	2,817(6,211)	3,660(8,068)
Paper	30.4	76,489(168,630)	23,253(51,264)	53,236(117,367)
Plastic	16.1	11,412(25,159)	1,837(4,051)	9,575(21,108)
Textiles	10.0	2,313(5,100)	231(510)	2,082(4,590)
Wood	14.4	1,696(3,740)	244(539)	1,452(3,201)
Ferrous	5.9	15,113(33,318)	892(1,966)	14,221(31,352)
Aluminum	3.8	2,776(6,120)	105(233)	2,671(5,887)
Glass	1.3	18,197(40,118)	237(522)	17,960(39,596)
Inert	--	617(1,360)	--- (--)	--- (--)
Fines	23.7	8,791(19,380)	2,083(4,593)	6,708(14,786)
Total	24.0	154,213(339,980)	37,320(82,278)	116,276(256,342)

Test period - October

Category	Weekly average moisture* (%)	Weekly total weight kg(lb)	moisture weight kg(lb)	Dry weight kg(lb)
Food waste	62.7	13,880(30,600)	8,703(19,186)	5,177(11,414)
Garden	54.2	6,123(13,500)	3,319(7,317)	2,805(6,183)
Paper	21.7	110,019(242,550)	23,874(52,633)	86,145(189,917)
Plastic	13.3	17,758(39,150)	2,362(5,207)	15,396(33,943)
Textiles	15.2	4,491(9,900)	683(1,505)	3,808(8,395)
Wood	12.	2,041(4,500)	249(549)	1,792(3,951)
Ferrous	7.0	17,962(39,600)	1,257(2,772)	16,705(36,828)
Aluminum	11.8	6,532(14,400)	771(1,699)	5,761(12,701)
Glass	4.0	15,513(34,200)	621(1,368)	14,892(32,832)
Inert	1.0	612(1,350)	6(14)	606(1,337)
Fines	34.7	8,369(18,450)	2,904(6,402)	5,465(12,048)
Total	22.0	203,300(448,200)	44,748(98,652)	158,553(349,549)

* Weekly averages computed from Table A-2, Daily Refuse Moisture Samples, in Appendix A.

As shown in Tables 5 and 6, the refuse in the October tests had more paper and plastic (the refuse categories affecting the heating value the most) per pound of refuse than the refuse in both the March and May tests, but less moisture than the refuse in the May tests (22 percent for October and 24 percent for May). The lesser moisture in the October tests was due principally to the lower moisture in the paper category.

TABLE 6. NORTH LITTLE ROCK DAILY REFUSE COMPOSITION FOR OCTOBER TESTS

	Daily Percentage						Standard Deviation (σ)	Total Weekly wt (kg)	Total Weekly wt (lb)
Category	10/6	10/9	10/10	10/11	10/12	Avg			
Food waste	6.3	12.3	6.9	6.5	1.8	6.8	-	13,880	30,600
Garden waste	0.4	4.9	4.2	3.2	0.3	2.6	-	5,307	11,700
Paper waste	55.4	47.3	53.1	56.6	58.3	54.1	3.8	110,631	243,960
Plastics	6.9	8.8	7.7	8.9	11.0	8.7	-	17,774	39,150
Textiles	0.2	2.1	3.8	1.9	1.3	1.9	1.2	3,878	8,550
Wood	0.6	0.7	0.8	0.2	2.3	0.9	0.7	1,837	4,050
Ferrous	8.4	10.1	9.9	7.6	7.5	8.7	1.1	17,758	39,150
Aluminum	0.3	2.8	2.0	2.6	7.7	3.0	-	6,123	13,500
Glass	11.2	7.2	3.8	10.3	8.2	8.1	2.6	16,738	36,900
Inert	0.6	0.1	0.7	0	0.1	.3	-	612	1,350
Fines	9.5	3.6	7.1	2.4	1.3	4.8	3.1	9,798	21,600
						99.9		204,367	450,450

On the average, the city collected 1 1/2 truck loads per day of waste from businesses and commercial establishments throughout the week. The waste averaged 3405 kg/day (7500 lb/day) and constituted 10 percent of the total refuse per week.

While the foregoing characteristics are for the March, May, and October tests, those following are for the detailed October tests only, as mentioned in the introduction.

As shown in Table 7, the daily bulk densities averaged 97.7 kg/m^3 (164.6 lb/yd^3).

TABLE 7. NORTH LITTLE ROCK DAILY REFUSE BULK DENSITIES FOR OCTOBER TESTS

Date	Bulk density (Average of ten samples) (kg/m^3)	(lb/yd^3)
10/09/78	101.40	170.90
10/10/78	86.29	145.40
10/11/78	102.86	173.40
10/12/78	100.17	168.80
Weekly average	97.70	164.60

Table 8 lists the results of the ultimate analysis of a refuse sample taken on October 9. This table shows that the sample carbon, oxygen, and sulfur percentages were close to the corresponding published values.

Again with the published values given for comparison, Table 9 lists the daily heating values of the refuse categories. Similarly, Table 10 compares the weekly heating values with the published values. The difference between the respective weekly totals is only 12,660 MJ (12 MBtu). The refuse categories that contributed most to the total heat value were paper and plastics with 68 and 18 percent, respectively, of the total percentage. Since the published values fall within the range of the laboratory-derived heating values, the latter were used in the efficiency analysis whenever possible.

The heating values for the entire refuse samples averaged 14.3 MJ/kg (6151 Btu/lb) on a dry basis and 11.1 MJ/kg (4777 Btu/lb) on an as-received basis. These values are higher than those found in most other refuse studies and can be attributed to the high percentage of paper and plastics in the refuse delivered to the North Little Rock plant.

The refuse burned during the Ocotber test totaled 204,300 kg (450,000 lb). Although the daily waste delivered was recorded, the daily feed rate had to be averaged as discussed above. During the October tests, the feed rate varied between 1552 and 1652 kg/hr (3420 and 3640 lb/hr) or 826 and 890 kg/unit (1820 and 1960 lb/unit) (see Table 11).

TABLE 8. NORTH LITTLE ROCK REFUSE CATEGORY ULTIMATE ANALYSIS FOR OCTOBER TESTS

		Element											
Category	Dry Wt (kg)	C (%)	Wt C (kg)	H (%)	Wt H (kg)	O (%)	Wt O (kg)	N (%)	Wt N (kg)	S (%)	Wt S (kg)	Ash (%)	Wt Ash (kg)
Food	5,177	18.09	937	11.96	619	53.53	2,771	3.65	189	.20	10	12.57	651
Garden	2,805	59.71	1,675	8.13	228	22.07	619	.94	26	.19	5	8.96	251
Paper	86,145	47.36	40,798	7.11	6,125	37.58	32,373	.09	78	.10	86	7.76	6,685
Plastics	15,396	55.97	8,617	7.29	1,122	25.79	3,971	1.60	246	.20	31	9.15	1,409
Textiles	3,808	56.54	2,153	6.91	263	31.52	1,200	1.46	56	.19	7	3.38	129
Wood	1,792	53.85	965	6.85	123	37.13	665	.45	8	.07	1	1.65	30
Fines	5,465	19.54	1,068	9.56	522	5.52	302	1.40	77	.20	11	63.78	3,486
Ferrous	16,705	0.8	134	0.04	--	0.20	34	--	--	--	--	99.0	16,538
Nonferrous	5,761	0.8	46	0.04	--	0.20	--	--	--	--	--	99.0	5,703
Glass	14,892	0.6	90	0.03	4	0.10	15	--	--	--	--	99.3	14,788
Inerts	606	20.6	125	2.6	16	4.0	24	.5	3	.01	--	72.3	438
Total dry (kg) Total dry (lb)	158,552 348,814		56,608 124,538		9,022 19,848		41,974 92,342		834 1,834		151 332		50,108 110,238
% of total (as received)		27.7		4.4		20.5		.41			.07		24.5
Published value % (as received) of total		28		3.5		22.4		.33			.16		25

TABLE 9. NORTH LITTLE ROCK DAILY REFUSE CATEGORY HEATING VALUES FOR OCTOBER TESTS

	Heating value MJ/kg(Btu/lb)					
	Date					
Category	10/9	10/10	10/11	10/12	Average	Published value
Garden	15.25(6,555)	18.01(7,742)	16.84(7,239)	18.58(7,988)	17.17(7,381)	17.45(7,500)
Food	19.86(8,539)	17.04(7,327)	14.73(6,334)	18.74(8,058)	17.60(7,565)	19.73(8,484)
Paper	18.28(7,859)	17.08(7,345)	18.71(8,042)	16.33(7,021)	17.60(7,567)	17.61(7,572)
Wood	19.44(8,358)	20.11(8,644)	19.61(8,431)	15.33(6,590)	18.62(8,006)	20.03(8,613)
Fines	12.00(5,159)	8.45(3,631)	8.34(3,587)	4.38(1,884)	8.29(3,565)	6.98(3,000)
Plastics	29.46(12,667)	27.12(11,661)	33.48(14,394)	26.44(11,367)	29.13(12,522)	28.36(12,194)
Textiles	18.78(8,074)	19.74(8,485)	19.34(8,315)	23.49(10,100)	20.34(8,744)	17.80(7,652)

TABLE 10. NORTH LITTLE ROCK REFUSE CATEGORY ENERGY VALUES FOR OCTOBER TESTS

Category	Percent of total by wt	Dry wt. kg (lb)	Laboratory		Published		Percent of total energy value	
			Heating value MJ/kg (Btu/lb)	Total energy MJ x 10^6 (Btu x 10^6)	Heating value MJ/kg (Btu/lb)	Total energy MJ x 10^6 (Btu x 10^6)	Laboratory	Published
Garden	3.0	2,805 (6,183)	17.17 (7,381)	.1062 (45.64)	17.45 (7,500)	.1079 (46.37)	2.1	2.2
Food	6.8	5,177 (11,414)	17.60 (7,565)	.2009 (86.35)	19.73 (8,484)	.2252 96.84)	4.0	4.5
Paper	53.9	86,145 (189,917)	17.60 (7,567)	3.3427 (1437.10)	17.61 (7,572)	3.3449 (1438.05)	66.8	67.3
Wood	1.0	1,792 (3,951)	18.62 (8,006)	.0736 31.63	20.03 (8,613)	.0792 34.03)	1.5	1.6
Fines	4.1	5,465 (12,048)	8.29 (3,565)	.0999 (42.95)	6.98 (3,000)	.0841 (36.14)	2.0	1.7
Plastics	8.7	15,396 (33,943)	29.13 (12,522)	.9886 (425.03)	28.36 (12,194)	.9627 413.90)	19.8	19.4
Textiles	2.2	3,808 (8,395)	20.34 (8,744)	.1708 73.41	17.80 (7,652)	.1494 (64.24)	3.4	3.0
Aluminum	3.2	5,761 (12,701)	.29 (124)	.0037 (1.57)	.29 (124)	.0037 (1.57)	.1	.1
Ferrous	8.8	16,705 (36,838)	.29 (124)	.0163 (4.57)	.29 (124)	.0163 (4.57)	.2	.2
Inerts	0.3	606 (1,337)	---	---	---	---	---	---
Glass	7.6	14,892 (32,832)	.15 (65)	.0050 (2.13)	.15 (65)	.0050 (2.13)	.1	.1
Total	100	158,443 (349,549)	129.47 (55,663)	5.0009 (2150)	128.69 (55,328)	4.9730 (2138)		

TABLE 11. NORTH LITTLE ROCK DAILY REFUSE BURNING RATES FOR OCTOBER TESTS*

Test period		Refuse burned kg(lb)	Refuse delivery date	Test time (hr)	Refuse processed kg(lb)	Burning rate Mg/hr(TPH)
Date	Time					
10/08	23:00			0		
		21,183(46,701)	10/06			
		37,494(82,660)	10/09			
10/10	10:30			35.5	58,681(129,370)	1.65(1.82)
		46,539(102,600)	10/10			
		41,558(91,620)	10/11			
10/12	12:00			49.5	88,097(194,220)	1.78(1.96)
		41,522(91,540)	10/12			
		23,151(51,040)	10/13			
		-6,804(-15,000*)	10/14			
10/13	21:30			33.5	57,869(127,580)	1.72(1.90)
Total		204,647(451,170)		118.5	204,647(451,170)	1.72(1.90)

* Weight of refuse not burned calculated by dividing estimated remaining volume by average bulk density from sort data.

Residue Characterizing

Residue Sampling and Analysis--

The residue discharged by each of the two residue conveyor drop chutes was dumped into containers. The residue weight was determined by weighing the residue removal truck with a full container and again with the container empty after the truck returned from the landfill. With each container having an identification number, the following record was kept: its placement under one or the other of the two drop chutes and its time of residue receipt and removal onto a truck.

At both of the drop chutes, residue samples were taken as follows: First the drop chute was pulled beyond the container area so that residue would fall onto the concrete floor. Large clinkers were broken into small pieces by a sledge hammer. Next the residue was mixed by shoveling the edges toward the center until the pile was completely turned over. Then the pile was quartered and the residue in opposite corners was shoveled into a container. After the remaining residue was mixed, the procedure was repeated until there was only enough residue to fill a 5-gal can. Then after the can was weighed to determine the residue bulk density, the sample was screened with a 1-in. mesh to separate the residue into a large fraction, which was mostly cans and glass, and a fine fraction, which was mostly the combusted refuse.

The moisture content of both fractions was determined on site by weighing a small tray full sample of each fraction, drying it overnight at 105° C, and then reweighing it.

Several larger samples of the fine fraction were placed in 1-qt sealed containers and retained for analysis. At the SYSTECH laboratory, the residue in each container was dried overnight at 105° C and then milled until the residue passed through a 5-mm mesh screen. One batch of the milled residue was used to conduct a total combustibles test for unburned volatiles and carbon. A small portion of a second batch was retained while the larger part was placed in a lysimeter to produce leachate. Then the second batch with its two-fold content of intact residue and leachate was sent to a commercial laboratory for the chemical and physical analysis of both the residue and the leachate. Finally, a third batch was sent to another commercial laboratory for the proximate analysis of the residue to determine its ash, carbon, volatile, sulfur, and Btu content.

Residue Characteristics--

Table 12 summarizes the residue characteristics for each of the three field tests.

The daily residue weights are summarized in Table 13. This table reflects the start-up effect on the rate of residue generation.

As seen in Table 14 for the residue size distribution, the fine fraction averaged 69 percent by weight of the residue generated during the three field tests. The bulk densities of the residue samples averaged 896 kg/m^3 (1510 lb/yd^3) with a standard deviation of 145 kg/m^3 over the 24 samples.

TABLE 12. NORTH LITTLE ROCK WEEKLY AS-RECEIVED RESIDUE CHARACTERISTICS FOR MARCH, MAY, AND OCTOBER TESTS

Test period	Refuse burned kg(lb)	Residue removed kg(lb)	Refuse % reduction by weight	Residue		
				Percent water	Percent ash	Percent combustibles
March	148,916(328,304)	115,630(254,920)	27.4	35.7	58.3	5.9
May	154,212(339,980)	78,651(173,396)	49.0	35.5	57.7	6.8
October	204,117(450,000)	91,834(202,460)	55.1	32.4	61.7	5.9
Total	507,245(1,118,284)	286,115(630,776)				

TABLE 13. NORTH LITTLE ROCK DAILY RESIDUE GENERATION RATES FOR OCTOBER TESTS

	Unit #3					Unit #4					
Date	Time	Box	Net weight kg(lb)	ΔTime* (hr)	Residue weight kg/hr(lb/hr)	Time	Box	Net weight kg(lb)	ΔTime* (hr)	Residue weight kg/hr(lb/hr)	Calculated daily wt total for Units 3 & 4 kg/day(hr/day)#
10/08	23:00				Test Start						
10/09	20:00	?	5,602(12,340)	21.00	267(588)	21:35	?	5,666(12,480)	22.58	242(533)	12,432(27,384)
10/10	---	---	--- (---)	---	---(---)	19:00	3	7,091(15,620)	21.55	329(725)	13,969(30,768)
10/11	00:45	1	7,264(16,000)	28.75	707(1,557)	06:30	V	5,793(12,760)	11.50	504(1,110)	21,476(47,304)
10/11	19:45	4	7,427(16,360)	19.00	391(861)	---	---	--- (---)	---	---(---)	
10/12	07:40	0	6,302(13,880)	11.92	528(1,164)	00:30	VII	5,657(12,460)	18.00	314(692)	19,722(43,440)
10/12	22:07	1	6,665(14,680)	14.45	461(1,016)	17:20	VI	5,502(12,120)	16.83	327(720)	
10/13	13:00	4	6,819(15,020)	14.90	458(1,008)	06:45	2	7,119(15,680)	13.42	530(1,168)	21,291(46,896)
10/13	---	---	--- (---)	---	---(---)	22:45	V	5,266(11,600)	16.00	329(725)	
10/14	?	VI	6,211(13,680÷)	?	---(---)	?	2	3,532(7,780÷)	?	---(---)	5,395(11,884)
Total	---	---	46,290(101,960)	118.50	390(860)	---	---	45,672(100,500)	118.50	385(848)	93,826(206,666)

* Does not include burndown time.

# Does not equal total of 202,460 lbs because of averaging to obtain some daily values.

÷ Residue in unit when test stopped.

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TABLE 14. NORTH LITTLE ROCK DAILY RESIDUE SIZE DISTRIBUTIONS FOR MARCH, MAY, AND OCTOBER TESTS

	Fraction	
Date	Large kg(lb)	Small kg(lb)
03/20/78	4.42(9.75)	7.03(15.50)
03/20/78	3.74(8.25)	5.10(11.25)
03/21/78	2.67(5.00)	10.32(22.75)
03/21/78	2.15(4.75)	8.85(19.50)
03/22/78	5.33(11.75)	11.00(24.25)
03/22/78	1.81(4.00)	8.39(18.50)
05/22/78	6.44(14.20)	14.02(30.90)
05/22/78	3.63(8.00)	7.89(17.40)
05/23/78	10.16(22.40)	19.50(43.00)
05/23/78	15.60(34.40)	19.46(42.90)
05/24/78	9.03(19.90)	19.05(42.00)
05/24/78	10.93(24.10)	23.63(52.10)
05/25/78	6.21(13.70)	16.33(36.00)
05/25/78	7.53(16.60)	19.32(42.60)
10/09/78	4.40(9.70)	11.19(24.66)
10/09/78	7.36(16.22)	23.28(51.32)
10/10/78	22.91(50.50)	58.74(129.50)
10/10/78	24.72(54.50)	44.23(97.50)
10/11/78	18.82(41.50)	38.10(84.00)
10/11/78	23.81(52.50)	68.95(152.00)
10/12/78	17.51(38.60)	48.17(106.20)
10/12/78	34.70(76.50)	59.60(131.40)
10/13/78	28.85(63.60)	67.72(149.30)
10/13/78	12.16(26.80)	33.70(74.30)
Total	284.50(627.22)	643.57(1,418.83)
Percent	31	69

The effectiveness of refuse reduction is the percentage of incinerator-fed combustibles that are burned. From the field test data and laboratory results, the following values were calculated: (1) the total dry residue was 62,043 kg (136,660 lb), (2) 69 percent or 42,810 kg (94,295 lb) of the residue was the small fraction (less than 1 inch), (3) 12.7 percent or 5437 kg (11,975 lb) of the residue small fraction was combustibles, (4) 24.5 percent or 50,048 kg (110,238 lb) of the refuse was ash and, (5) 154,252 kg (339,762 lb) of the refuse was combustibles. These calculations are found in Appendix B.

From this data the amount of ash in the residue was computed by subtracting the weight of unburned combustibles from the total dry weight of residue measured. This value was 56,607 kg (124,685 lb). The effectiveness was expressed as follows:

$$E = 1 - \frac{\text{unburned combustibles weight}}{\text{input combustibles weight}}$$

Substituting the foregoing calculated values yields an effectiveness of 96 percent.

The 56,607 kg (124,685 lb) of ash is more than the calculated input ash of 50,048 kg (110,238 lb) from the ultimate analysis. The difference could be due to errors in measuring the residue moisture or to the large fraction residue containing some combustibles. If the residue moisture was 40 rather than 32.5 percent, then (1) the dry weight would be 55,150 kg (121,476 lb), (2) the combustibles in the small fraction would be 4833 kg (10,645 lb), and (3) the weight of ash in the refuse would be 50,317 kg (110,831 lb) or about that calculated in the refuse.

With these values substituted in the above equation, the effectiveness would be 97 percent.

If the large fraction contains the balance of combustibles, then the effectiveness would be 93 percent.

TABLE 15. NORTH LITTLE ROCK DAILY RESIDUE COMPOSITION FOR MARCH, MAY, AND OCTOBER TESTS

	Moisture content (%)*		Ash content (%)#		Combustible content (%)#	
Date	Unit 3	Unit 4	Unit 3	Unit 4	Unit 3	Unit 4
03/20	31.6	24.1	62.0	62.0	10.1	10.1
03/21	44.7	40.2	44.8	44.8	12.7	12.7
03/22	50.0	37.0	40.5	40.5	16.0	16.0
03/23	36.0	38.5	48.3	48.3	14.4	14.4
05/22	36.6	43.8	57.5	50.8	5.9	5.4
05/23	24.9	33.4	69.1	62.8	6.1	3.8
05/24	21.5	36.7	64.5	56.6	14.0	6.7
05/25	54.2	37.4	39.7	52.5	6.1	10.1
10/09	40.3	49.9	47.8	43.6	11.9	16.5
10/10	--	--	--	--	13.3	9.5
10/11	16.0	30.3	76.4	60.9	7.6	8.8
10/12	31.3	20.0	51.0	68.9	17.7	11.1
10/13	35.4	36.2	48.0	49.6	16.6	14.2
Average	33.4	34.6	57.7	56.9	11.7	10.7

* Values for 3/20 through 5/25 are based on large fraction moisture data of 3/20; values for 10/09 through 10/13 are direct measurements of large fraction.

# Values for 3/20 through 3/23 are the same for Units 3 and 4 since they were obtained from a combined Unit 3 and Unit 4 sample.

The SYSTECH laboratory analysis shown in Table 15 and the commercial laboratory proximate analysis shown in Table 16 found closely agreeing results of 12.6 and 12.7 percent by weight, respectively, of unburned combustibles in the dry small residue fraction. The proximate analysis also revealed that the average heating value of the residue was 3.17 MJ/kg (1363 Btu/lb) with 2.86 and 9.7 percent of the residue being carbon and volatiles, respectively.

TABLE 16. NORTH LITTLE ROCK DAILY RESIDUE PROXIMATE ANALYSIS (DRY BASIS) FOR OCTOBER TESTS

		Date					
Component		10-9	10-10	10-11	10-12	10-13	Average
Moisture	(%)	1.19	1.38	0.98	1.90	1.32	1.35
Volatile matter	(%)	11.62	7.73	5.87	11.89	12.08	9.8
Ash	(%)	83.39	88.13	90.44	86.21	81.57	85.95
Fixed carbon	(%)	3.80	2.76	2.71	0	5.03	2.86
Sulfur	(%)	0	0	0	0	0	0
Heating value	MJ/kg	4.74	2.04	1.66	2.12	5.29	3.17
	(Btu/lb)	(2038)	(875)	(714)	(913)	(2274)	(1363)
Total combustibles	(%)	15.42	10.49	8.58	11.89	17.11	12.66

System Mass Balance

The system mass balance compares the mass flows entering and leaving the incinerator-heat recovery system. While the system inputs measured were the refuse, the combustion air, the auxiliary gas, the residue cooling water, and the aspirator fan air, the system outputs measured were the residue, the boiler exhaust stack flue gas, and the dump stack flue gas. With Appendix B detailing the mass calculations, the mass balance diagram in Figure 36 summarizes the results on a per ton of refuse input basis. Over the 118.5-hour test, the mass input was 4127 Mg (4550 tons) and the mass output was 4199 Mg (4629 tons). The difference, namely 71.7 Mg (79 tons) or 2 percent of the output, was not accounted for.

Water Balance--

Since the system mass balance can be divided into balances on each of the components entering and leaving the system, the water balance was calculated to confirm the validity of the moisture values used in the energy efficiency calculations.

The water inputs were moisture in the refuse, moisture in the combustion air, and hydrogen in the refuse which combined with oxygen to form water. The water output in the stack flow was measured by taking the difference between the final and the initial weight of the liquid in the impingers of the modified Method 5 gas train. This additional weight represents condensed water or the moisture captured in the impingers.

Mass balance 118.5-hour test*

Source	Input: Mg per Mg refuse or Ton per ton refuse	Input: % of Total	Output: Mg per Mg refuse or Ton per ton refuse	Output: % of Total
Refuse	1.0	4.92		
Natural gas	0.002	0.01		
Residue, cooling water	0.157	0.77		
Aspirator air	10.26	50.54		
Blower air	8.88	43.76		
Residue, wet			0.45	2.19
Flue gases			20.13	97.81
Total	20.299	100.00	20.58	100.00

* Total refuse input 204 Mg (225 tons).

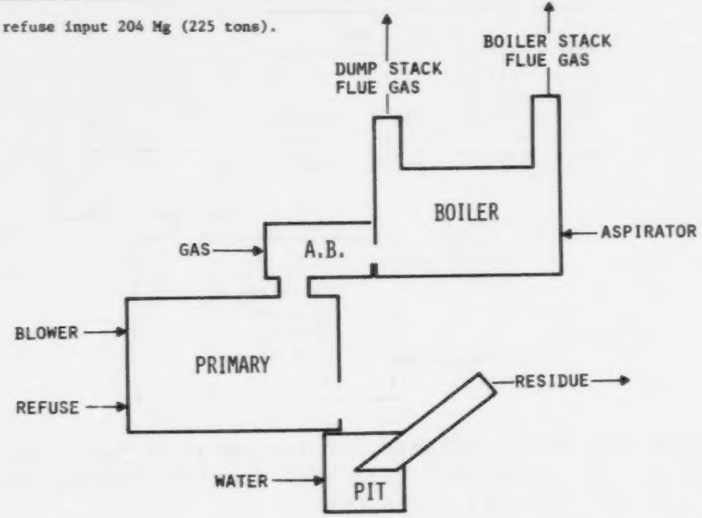


Figure 36. Mass balance for incineration-heat recovery processes in North Little Rock facility during the 118.5-hour October field test.

As shown in the water balance in Figure 37, the water input weight was 132.6 Mg (146.2 tons) and the water output weight was 148.9 Mg (164.2 tons). That the output weight was 16.3 Mg (18 tons) or 11 percent more than the input weight was due to variations in the amounts of the samples measured. The stack gas samples monitored were a small part of the total flow, and they varied from 5 to 7 percent of moisture by volume. Therefore, the water entrained in the stack gases could have been 10 percent higher or lower by weight than the average value used.

Combustion Product Balance--

The combustion product balance was calculated to verify (1) the measurements used to compute the stack flow in the system mass balance, namely, the gas flow rate and the percentage of water by volume as measured by the Method 5 train and the percentages of oxygen, carbon monoxide, and carbon dioxide in the flue gas as measured by the tri-gas, Orsat, and infrared monitors; and (2) the amounts of carbon, hydrogen, sulfur, nitrogen, and oxygen in the refuse as determined by the sort characteristic analysis and the ultimate analysis.

Since the elements found in the ultimate analysis combine with oxygen to form carbon dioxide, carbon monoxide, water vapor, nitrogen oxides, and sulfur oxides, the comparison of the combined weight of the elements with the measured weight of the stack flow is the expression for the combustion product balance.

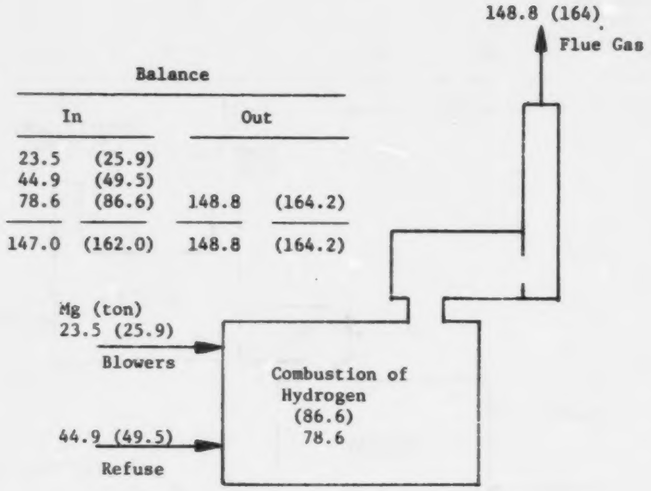


Figure 37. Water balance for incineration-heat recovery processes in North Little Rock facility during the 118.5-hour October field test.

The combustion product balance in Table 17 shows the amounts of the elements and their combustion products. The stack mass flow of 3827 Mg (4218 tons) was taken from the system mass balance. The total calculated mass flow into the incinerator was 3816 Mg (4205 tons) with 1782 Mg (1964 tons) from the combustion product gases and 2045 Mg (2254 tons) from the aspirator fan.

Excess Air--

The amount of oxygen in the flue gases exiting the boiler reflects the condition of the combustion processes within the incinerator. Any oxygen content obviously indicates that more oxygen was introduced than needed (an excess air condition) and that sensible heat was lost in the stack gases. The excess air was calculated by substituting data from the flue gas analysis in the following equation:

$$\text{Excess air} = 100 \times \frac{O_2 - CO/2}{0.264N_2 - (O_2 - CO/2)}$$

During the third field test the average values obtained by the tri-gas and NDIR recorder for the dry flue gas analysis were as follows:

CO_2 = 9.5%
O_2 = 10.7%
CO = 0
$N_2 = [100 - (CO + CO_2 + O_2)] = 79.8\%$

Substituting these values in the equation above yields an average excess air amount of 103 percent. Daily values of excess air ranged from 92 to 117 percent.

TABLE 17. NORTH LITTLE ROCK COMBUSTION PRODUCTS BALANCE FOR OCTOBER TESTS

Source	Input		Output	
	Mg	(ton)	Mg	(ton)
Refuse				
Moisture	46	(51)		
C	57	(63)		
H	9	(10)		
O	42	(46)		
N	1	(1)		
Combustion air				
Moisture	25	(27)		
O	373	(411)		
N	1218	(1343)		
Natural gas	<1	(<1)		
Aspirator air	2045	(2254)	2045	(2254)
Flue gases*				
H_2O			149	(164)
CO_2			228	(251)
O			187	(206)
N			1218	(1343)
Total	3816	(4205)	3827	(4218)

*SO_x, NO_x, and CO were all less than 0.1 percent

Energy Balance

The energy balance compares the measured energy inputs and outputs. For this balance, the inputs were refuse, electricity, and auxiliary fuel while the outputs were steam, sensible heat and remaining energy in the residue, heat lost by radiation and convection, and sensible heat in the flue gases. Appendix B details the energy input and output calculations, and Figure 38 summarizes the results on an MBtu per 1 ton of refuse input basis. The energy inputs and outputs for the 118.5-hour test totaled 2298 and 2350 GJ (2178 and 2228 MBtu), respectively. The larger energy ouput of 52 GJ (50 MBtu) or 2 percent of the energy input was well within the expected ±5 percent range.

Energy balance 118.5-hour test *

Source	Input: GJ per Mg of refuse	Input: (MBtu per Ton of refuse)	Input: % of total	Output: GJ per Mg of refuse	Output: (MBtu per Ton of refuse)	Output: % of total
Refuse	11.12	(9.56)	98.71			
Electricity	.09	(.08)	0.83			
Natural gas	.052	(.044)	0.46			
Unburned combustibles				.661	(.569)	5.74
Steam				5.99	(5.15)	52.05
Flue gases				4.30	(3.70)	37.36
Radiation and Convection				0.56	(0.48)	4.85
Total	11.262	(9.684)	100.00	11.51	(9.909)	100.00

*Total refuse input 204 Mg (225 ton)

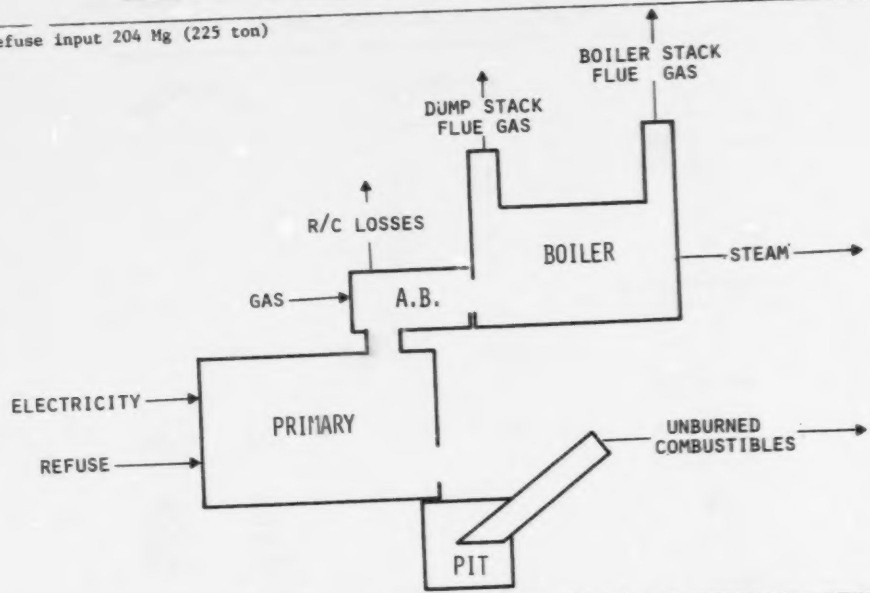

BOILER STACK FLUE GAS
DUMP STACK FLUE GAS
R/C LOSSES
BOILER
STEAM
GAS
A.B.
ELECTRICITY
PRIMARY
REFUSE
UNBURNED COMBUSTIBLES
PIT

Figure 38. Energy balance for incineration-heat recovery processes in North Little Rock facility during the 118.5-hour October field test.

Combustion Efficiency

Efficiency of Refuse Combustion--

The combustion efficiency of the refuse on a dry basis was calculated as follows:

$$\eta = 1 - Q_r/Q_t$$

where Q_t = total refuse energy
Q_r = sensible heat and remaining energy in the residue

Substituting the values for Q_r and Q_t, as given in the energy balance in Figure 38, in the equation gives an efficiency of 94 percent. This value compares well with the effectiveness of refuse reduction calculated earlier.

Efficiency of Incinerator System--

The efficiency of the incinerator system is that percentage of the total energy in the refuse and combustion air which after its conversion to hot gases was available for the heat recovery system. Using the heat loss method, the efficiency was computed by:

$$\eta = 1 - \frac{Q_r + Q_w + Q_{rc}}{Q_t}$$

and the net efficiency was computed by:

$$\text{net } \eta = 1 - \frac{Q_r + Q_{rc}}{Q_t - Q_w}$$

where Q_r = sensible heat and remaining energy in the residue because of unburned combustibles

Q_w = latent heat of vaporization of moisture in the refuse plus the energy loss due to hydrogen combination

Q_{rc} = heat lost by radiation and convection up to the boiler section

Q_t = total input energy

The substitution of the energy balance values in the above equation yields an incinerator efficiency of 76 percent and a net efficiency of 87 percent.

Energy Recovered

Steam Quantity and Quality--

The quantity of steam produced per unit time was determined as follows: Readings of the meter in the incoming city water line and of the meter in the condensate return line were recorded to determine the volume rate of the water converted into steam.

When the meter in the condensate return line malfunctioned during the third field test, the valve in this line was closed to the units being tested. Therefore, all water to the boiler was make-up water. The water lost during blowdowns was negligible and therefore ignored in the calculations.

During the 118.5 hours of the third field test, the boiler produced 443,703 kg (977,321 lb) of steam with an hourly average of 3744 kg (8,250 lb).

The pressure in the steam drum, as shown in Figure 39, varied from 120 psi at peak steam demand to 130 psi at the average steam demand to a high of 140 psi at the low steam demand.

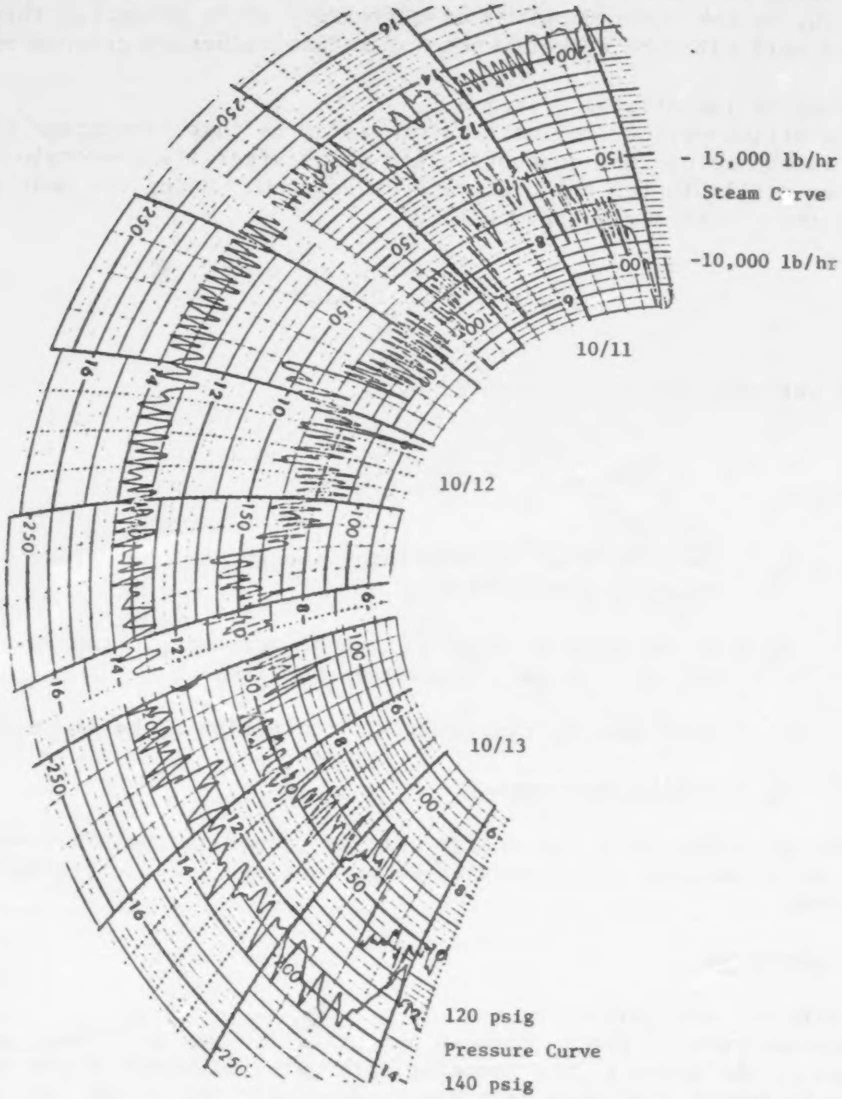


Figure 39. Steam output versus steam drum boiler pressure in North Little Rock facility.

The quality of the steam was periodically determined by taking readings from a calorimeter installed in a straight run of the steam line just after the line leaves the boiler. The calorimeter readings indicated that the steam enthalapy ranged from 2.72 to 2.73 MJ/kg (1172.5 to 1175 Btu/lb). The application of these calorimeter readings to the Mollier diagram revealed that the steam quality ranged from 98.75 to 99 percent.

In addition, during the third test run, steam was slowly bled from the calorimeter until a sample of condensate was captured. A 100-mℓ sample of the condensate was extracted for quality analysis. The condensate was analyzed, and no measurable solids were found.

System Energy Efficiency--

In the calculation of the system energy efficiency by the input-output method, the inputs were the energy in the refuse, the auxiliary fuel, and the electricity consumed by the incinerator and boiler; and the output was the energy in the steam generated. During the third test period, steam was generated during 95 percent of the test time. Consequently, to represent the optimum system performance, the input energy should be adjusted to 95 percent of its total value. Accordingly, the efficiency was calculated as follows:

$$\eta = \frac{\text{steam energy}}{\text{input energy (0.95)}} = 0.56$$

Therefore, the system energy efficiency during the third field test was 56 percent.

In the calculation of the system energy efficiency by the heat loss method, the quotient of the sum of the heat losses divided by the total heat input was subtracted from unity, that is,

$$\eta = 1 - \frac{\Sigma \text{ heat losses}}{\text{total heat input}}$$

From the energy balance for the test week, the heat losses were 1040 GJ (989 MBtu) and the total heat input was 2298 GJ (2178 MBtu). Substituting these values in the equation for the heat loss method gives an efficiency of 54 percent.

To compare the performance of this system more reasonably with the performance of other systems using refuse with less moisture and hydrogen content, the net efficiency with a lower heating value was calculated. The lower heating value is the heat input from combustion of refuse minus the heat lost in evaporating both the refuse moisture and the water formed by burning the hydrogen in the waste. During the third field test, the input mass of the refuse moisture was 44,946 kg (99,000 lb), and the water formed from the hydrogen weighed 78,542 kg (173,000 lb). The energy consumed in evaporating the moisture was 286,960 MJ (272 MBtu). The energy lost in the wet flue gases was 335,912 MJ (318 MBtu). Therefore, subtracting these values from the input and output totals in the energy balance yields the adjusted values of 2,026,000 MJ (1920 MBtu) and 2,032,000 MJ (1926 MBtu).

Consequently, the net efficiency as calculated by the input-output method was 61 percent, and as calculated by the heat loss method, the net efficiency was 61 percent.

In summary, the net efficiency is about 8 to 11 percent more than the efficiency for the as-received refuse.

Effectiveness of Boiler--

The effectiveness of the boiler is the ratio of the actual heat transfer rate in the exchanger to the thermodynamically limited maximum possible heat transfer rate which could be realized only in a counterflow heat exchanger of infinite heat transfer area. This can be expressed as follows:

$$E = \frac{T_{h_1} - T_{h_2}}{T_{h_1} - T_{c_1}}$$

where T_{h_1} = temperature of flue gas entering the boiler

T_{h_2} = temperature of flue gas exiting the boiler

T_{c_1} = temperature of feedwater entering the boiler

During the third field test, the T_{h_1}, T_{h_2}, and T_{c_1} temperatures averaged 982°, 232°, and 138° C (1800°, 450°, and 280° F), respectively. Consequently, the boiler effectiveness was 89 percent.

Thermal Efficiency of Boiler--

While the effectiveness is the theoretical maximum performance of the boiler, the actual operational efficiency was calculated as follows:

$$\eta = \frac{\text{heat transferred to steam}}{\text{sensible heat of gases into boiler}}$$

or

$$\eta = \frac{M_w\ (h_2 - h_1)}{M_g\ C_p\ (T_1 - T_2)}$$

where M_w = mass of water entering

h_2 = enthalpy of water leaving

h_1 = enthalpy of water entering

M_g = mass of flue gases entering

C_p = mean specific heat of flue gases

T_1 = temperature of flue gases entering

T_2 = temperature of flue gases leaving

The calculations are found in Appendix B. As calculated with the higher heating value of the flue gas, the efficiency was 71 percent, and as calculated with the lower heating value of the flue gas, the efficiency was 76 percent.

System Effectiveness

Refuse Handling Capability--

The Consumat incinerators proved capable of handling a wide variety of refuse sizes and components.

While the moisture content of the refuse ranged from 16 to 35 percent over the three field tests, the composition of the refuse varied little with no one component differing by more than 5 percent.

As the refuse was pushed into the loader hopper, most of it remained in plastic bags. Glass was a frequent operational hazard because of bottles broken during dumping, moving, and loading. In addition to manually removing such materials as pipe lengths, wire rolls, scrap metal, and compressed gas tanks from the floor-deposited refuse, the operator occasionally had to manually adjust large cardboard boxes dumped into the hopper. During the first two tests, clinkers formed by slag and metal jammed the residue transfer rams and the residue removal conveyor. However, when equipment modifications and operational changes were made after the first and second tests, there were few such jams during the third test.

Design and Actual Capacities--

Each of the incinerators was designed to handle 22.67 Mg/day (25 TPD) of municipal solid waste with a minimum of refuse sorting and handling before hopper loading. During the third field test, the refuse throughputs averaged 1725 kg/hr (3800 lb/hr). However, the loading rate varied somewhat because of two factors: (1) delays in the operators' responses to the ready-to-load light, and (2) various operators' interpretations of what constituted light, medium, and heavy loads. In addition, since there was no loading during shift changes, periods between loadings occasionally extended to 20 minutes.

Table 18 shows the refuse throughput averages for each of the three field tests. While the greater throughputs during the third test reflect the equipment and operational changes made after the second test, no significant changes were made after the third test to further increase the throughput rate.

TABLE 18. NORTH LITTLE ROCK MONTHLY TOTAL PLANT REFUSE FEED RATES

Period	Total weight processed Mg	Total weight processed (Tons)	Days	Average weight per day Mg	Average weight per day (Tons)
12/13/77 - 12/30/77	406.62	(448.22)	11	36.9	(40.7)
1/02/78 - 1/31/78	615.93	(678.95)	14	44.0	(48.5)
2/01/78 - 2/28/78	655.43	(722.49)	17	38.6	(42.5)
3/02/78 - 3/31/78	976.69	(1,076.62)	19	51.4	(56.7)
4/03/78 - 4/28/78	1,006.89	(1,109.91)	18	56.0	(61.7)
5/01/78 - 5/31/78	1,221.98	(1,347.00)	21	58.2	(64.1)
6/01/78 - 6/30/78	1,185.69	(1,307.00)	21	56.5	(62.3)
7/05/78 - 7/31/78	1,060.87	(1,169.41)	18	59.0	(65.0)
8/01/78 - 8/31/78	1,442.89	(1,590.51)	23	62.8	(69.2)
9/01/78 - 9/26/78	1,115.92	(1,230.09)	17	65.7	(72.4)
9/27/78 - 10/16/78	999.60	(1,101.87)	14	71.4	(78.7)
	10,688.51	(11,782.07)	193	55.4	(61.0)

Each of the two Consumat heat recovery modules was designed to produce 4540 kg/hr (10,000 lb/hr) of steam. During the first two test periods, mechanical deficiencies required using the auxiliary boiler to meet the steam demand. However, the equipment and operational changes made after the second test period were so effective that there has been no need for the auxiliary boiler after August 1978.

During the third field test, the total plant steam demand, as measured by the Honeywell steam flow integrator, averaged 4,994 kg/hr (11,000 lb/hr) with a maximum and minimum of 6,356 and 2724 kg/hr (14,000 and 6,000 lb/hr) On the average, the steam demand was 79 percent of the original anticipated demand of 6810 kg/hr (15,000 lb/hr). Also during the third field test, the west-end boiler steam outputs averaged 3746 kg/hr (8250 lb/hr) and reached levels between 4994 and 5357 kg/hr (11,000 and 11,800 lb/hr) during peak demand periods. These demands lasted for only 30 to 60 minutes.

Operation--

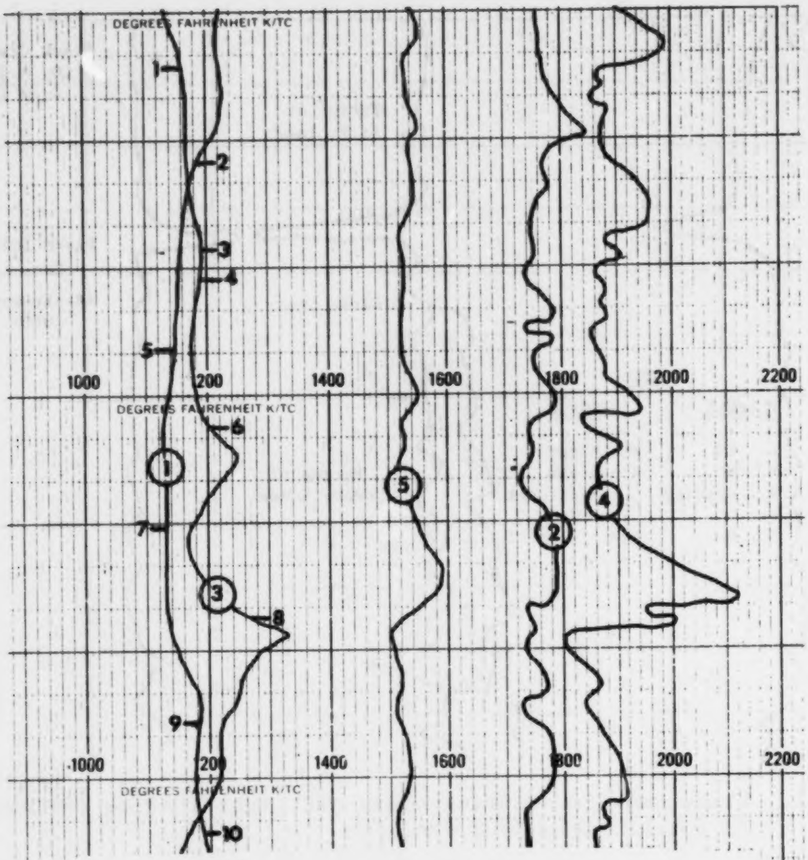
The operation of the facility required a total of nine personnel, i.e., one supervisor, one office manager, one truck driver, and six operators, two per shift for each of the three shifts. The supervisor position was critical to the successful operation of the plant. The office manager maintained all plant records such as utilities, refuse delivery, and steam consumption. The truck driver transported the residue to the city-owned disposal site. The two operators shared routine maintenance and incinerator loading operations. At the end of their shifts, the operators completed an operation summary which included (1) the number of loads put into each incinerator; (2) gas and water meter readings; and (3) comments on each incinerator's performance, the boiler performance, and the skid-steer loader's condition.

The effects on the system temperatures and gaseous emissions from varying the hopper loads from light to heavy are shown in Figures 40 and 41. The steady-state, efficient operation of the system requires that the operators closely follow the start-up procedures, the automatic loading instructions, and the burndown procedures.

Maintenance--

The routine maintenance of the facility required a working knowledge of the hydraulic, electronic, and mechanical systems. A supply of small spare parts, such as switches, thermocouples, hydraulic parts, and motors, was essential for continuous 24-hour operation. While major maintenance during the week required shutting down the incinerator, much maintenance could be performed during an hour or two with the incinerator still operating but at reduced capacity.

Normally, the following were performed during the weekend: system inspection, major maintenance (if required), and removal of soot deposits in the boiler.



LEGEND

① Temperature in Primary Chamber No. 3.
② Temperature in Secondary Chamber No. 3.
③ Temperature in Primary Chamber No. 4.
④ Temperature in Secondary Chamber No. 4.
⑤ Temperature at Boiler Entrance.

EVENTS

1. Load, light No. 4
2. Load, light No. 3
3. Load, medium No. 4
4. Residue dump No. 4
5. Load, light No. 3
6. Load, medium No. 4
7. Load, light No. 3
8. Load, medium No. 4
9. Load, medium No. 3
10. Load, medium No. 4

Figure 40. System temperature versus loading sizes and events in North Little Rock facility.

The boiler was opened and cleaned with a high pressure hose on the weekend. This action removed any soot buildup on the tubes and on the floor of the boiler. The fins on the boiler tubes were measured during the October test to determine the erosion effects. The results are shown in Table 19. Although the original depth of the fins was not available, the difference between the leading edge and the trailing edge dimensions shows the erosion that had occurred in less than a calendar year.

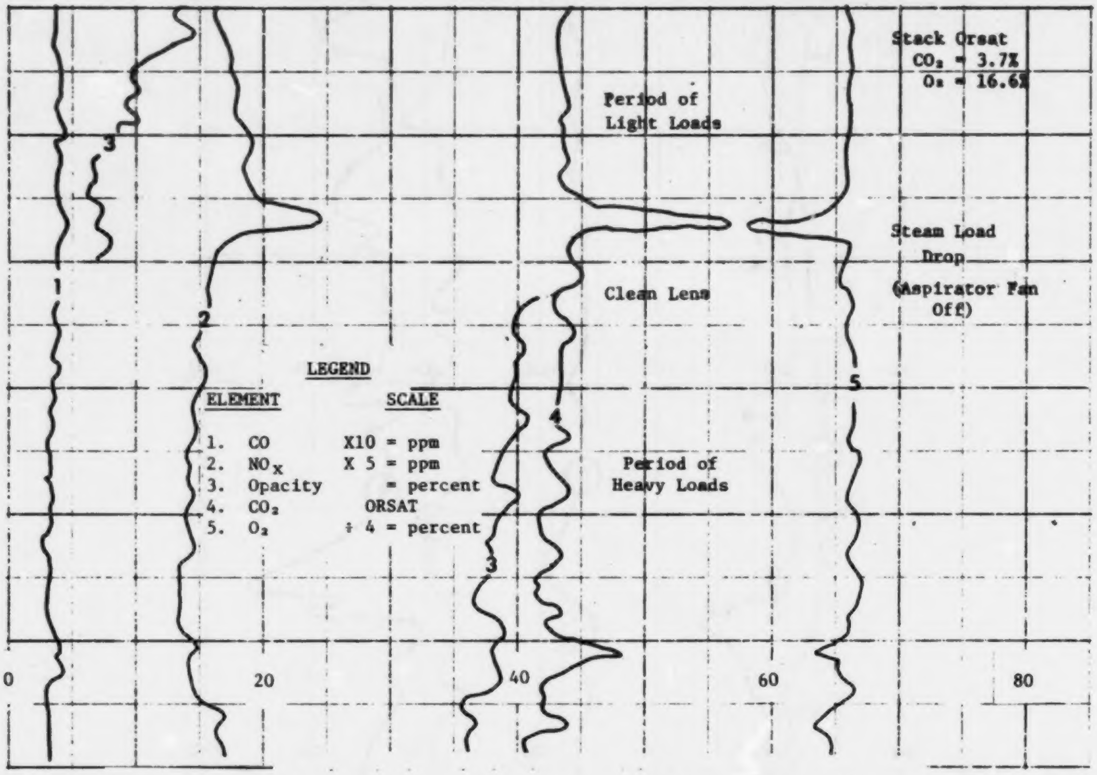


Figure 41. Stack emissions during heavy and light loading periods in North Little Rock facility.

TABLE 19. NORTH LITTLE ROCK BOILER TUBE FIN MEASUREMENTS FOR EROSION DETERMINATION

		Fin depth (mm)				
		Tube bank				
Date	Edge	1	2	3	4	5
New		None	NA	NA	NA	NA
October 1978	Leading	None	10	12	15	16
	Trailing	None	12	14	17	17
Erosion*		None	2	2	2	1

NA Not available.
* Erosion assumed to be difference between leading and trailing edge.

Environmental Analysis

Stack Emissions--

Except for periods when soot was blown off the boiler tubes, the flue gases exiting the boiler exhaust stack were sampled as follows: (1) periodically by the filter in the modified EPA Method 5 train to capture particulates and heavy metals in particulate form for mass flow rate and chemical composition analyses; (2) periodically by the impingers in the EPA Method 5, 7, or 8 train to capture heavy metal vapors, other vapors, and gases for mass flow rate and chemical composition analyses; (3) periodically by the 7-stage inertial cascade impactor to capture particulates for size distribution analysis; (4) continuously by the TSI Electro-Chemical Cell Monitor to analyze the concentrations of oxygen and nitrogen and sulfur oxides; (5) periodically by an Orsat analyzer; (6) periodically by the gas chromatograph to capture hydrocarbons for chemical composition and concentration analyses of the hydrocarbons in the C_1 to C_6 ranges; and (7) continuously by two Beckman nondispersive infrared analyzers to determine the levels of carbon dioxide and carbon monoxide.

To supply the foregoing monitors with flue gas samples, the EPA trains and the 7-stage cascade impactor were inserted in the boiler exhaust stack near the top; and flue gases were drawn through two ports, a condensation trap, and then through heated lines to the monitoring devices in the instrumentation trailer. Of these ports, one was near the top of the stack for continuous flue gas sampling during the day, and the other was at the ducting between the boiler gas outlet and the aspirator section gas inlet for continuous flue gas sampling during the night.

The emission sampling results for the October field tests are presented in Table 20, with all of the field tests summarized in Table 21. The emission factors for the October field test in pounds per ton of refuse charged are given in Table 22. Appendix A gives the results for the individual tests not presented here.

The flue gas velocities and temperatures averaged 22,860 ACFM and 141° C (286° F). On the average, the moisture in the flue gas was 6 percent of the total gas volume. Corrected to 12 percent CO_2, the particulate concentrations averaged 0.1553 gr/DSCF over 24 tests with the maximum and minimum being 0.2779 and 0.0669 gr/SCF. The size distribution analyses (see Figure 42) revealed that 95 percent by weight of the particulates were smaller than 7 μm, and 50 percent by weight were smaller than 0.3 μm. During the third test period, the total particulates, including wet-catch, as shown in Table 23, averaged 0.1740 gr/SCF with a maximum of 0.219 gr/SCF and a minimum of 0.119 gr/SCF.

During the third test period, a probe continuously monitored the flue gas opacity, but the measurements were recorded only periodically since particulates which quickly covered the optical surfaces had to be removed before each reading. The opacities averaged 24 percent with the maximum and minimum being 42 and 12 percent.

TABLE 20. NORTH LITTLE ROCK STACK EMISSION CONCENTRATIONS FOR OCTOBER TESTS

Parameter	Emissions		
	Maximum	Average	Minimum
Particulate* g/m^3 (gr/SCF)	.529 (.231)	.314 (.130)	.153 (.067)
Particulate g/m^3 (gr/SCF)	.163 (.071)	.101 (.044)	.045 (.019)
Particulate Size (μm)	28.0	0.3	<0.3
Chloride mg/m^3 (ppm)	193 (133)	155 (107)	127 (88)
Fluoride mg/m^3 (ppm)	1.2 (1.5)	.9 (1.2)	.5 (.6)
NO_x mg/m^3 (ppm)	214 (114)	130 (70)	57 (30)
SO_x mg/m^3 (ppm)	--	<13 (<5)	--
Total Hydrocarbons† mg/m^3 (ppm)	25.3 (38.6)	1.78 (2.72)	1.26 (1.92)
O_2 Percent	18	16.9	13.8
CO_2 Percent	6.8	4.4	2.6
CO mg/m^3 (ppm)	46.4 (40.3)	21.6 (18.8)	<11.0 (9.5)
H_2O Percent	7.5	6.0	4.2
Opacity Percent	42	24	12

* Corrected to 12% CO_2.

† as CH_4.

TABLE 21. NORTH LITTLE ROCK SUMMARY OF STACK EMISSIONS FOR MARCH, MAY, AND OCTOBER TESTS

	Field test											
	Test 1: March 3-20, 1978				Test 2: May 5-22, 1978				Test 3: October 9-13, 1978			
Emissions (units)	Max	Avg	Min	Std Dev	Max	Avg	Min	Std Dev	Max	Avg	Min	Std Dev
Particulate (gr/SCF)*	.1847	.1430	.0998	.0282	.2779	.1906	.0747	.0545	.2312	.1297	.0669	.0549
Particulate (g/m^3)*	.4227	.3458	.2284	.0682	.6359	.4609	.1709	.1318	.5291	.3136	.1531	.1327
Chlorides (mg/m^3)	609.9	344.7	217.0	126.8	34.9	26.0	19.4	6.0	193.3	154.8	127.4	24.2
Fluorides (mg/m^3)	4.3	2.3	1.6	1.0	1.7	1.3	.6	.5	1.2	.9	.5	.5
Stack O_2 (percent)	18.3	17.2	16.5	.8	19.0	17.1	15.1	.9	18.0	16.9	13.8	.8
Stack CO_2 (percent)†	3.5	3.1	2.8	.3	4.5	2.6	1.9	.7	4.7	4.1	3.5	.4
Stack CO_2 (percent)††		No Data				No Data			6.8	4.4	2.6	.9
Stack CO (mg/m^3)		No Data			61.4	35.2	16.6	9.4	46.4	21.6	<11.0	15.8
Stack NO_x (mg/m^3)	112.8	102.3	95.6	7.2	175.0	94.8	<10.0	39.8	213.9	129.7	57.3	38.1
Stack SO_x (mg/m^3)	13.3	13.3	13.3	0	33.3	10.3	<13.0	9.4	<13.0	<13.0	<13.0	0
Stack H_2O (percent by volume)	6.7	6.0	4.5	--	9.7	7.9	6.8	--	7.5	6.1	4.2	--
Boiler O_2 (percent)	--	11.6	--	--	14.5	11.5	9.2	1.7	12.6	10.7	8.8	.5
Boiler CO_2 (percent)††		No Data				No Data			11.6	9.5	7.5	.6
Boiler CO (mg/m^3)		No Data			61.7	44.6	25.8	10.4	91.6	37.4	<11.0	22.9
Boiler NO_x (mg/m^3)	334.3	272.2	181.5	56.3	510.0	284.4	76.6	114.4	450.8	386.9	192.9	58.4
Boiler SO_x (mg/m^3)	133.3	56.5	13.3	49.2	88.0	22.5	<13.0	19.4	26.6	3.3	<13.0	6.2
Particulate size (μm)#	34.0	3.0	<0.3	--	28.0	0.3	<0.3	--	28.0	0.3	<0.3	--
Hydrocarbons (mg/m^3)ϕ	0.19	0.16	0.15	--	0.19	0.12	0.06	--	25.3	1.78	1.26	--
Opacity (percent)		No Data				No Data			42	24	12	--
Flue gas temperature (°F)	259	249	234	--	260	242	217	--	289	285	274	--
Flue gas flow (SCFM)	19,313	15,671	13,975	--	18,883	15,822	12,260	--	18,658	16,185	15,192	--
Flue gas flow (CFM)	26,166	21,085	18,436	--	26,084	22,893	17,518		26,207	22,823	21,484	

* Corrected to 12 percent CO_2

† Data from Orsat analyser

# Average is mass mean diameter

ϕ Average of CH_4-C_4H_{10}

†† Continuous NDIR monitor

TABLE 22. NORTH LITTLE ROCK POLLUTANT EMISSION RATES FOR OCTOBER TESTS

	Emission rate			
Pollutant	Maximum	Average	Minimum	lb/ton refuse charged*
Particulate	.231† gr/SCF	.130† gr/SCF	.067† gr/SCF	3.03
SO_x		<10 ppm		<0.78
NO_x	99 ppm	82 ppm	69 ppm	3.68
CO	36 ppm	29 ppm	16 ppm	1.00
HC	40 ppm	28 ppm	20 ppm	0.55
Pb		4.49 mg/m^3		0.14

* Based on an average flow of 15,198 DSCFM including aspirator air and a feed rate of 1.9 TPH.

† Corrected to 12 percent CO_2.

TABLE 23. NORTH LITTLE ROCK TOTAL EMISSION CONCENTRATIONS FOR OCTOBER TESTS

	Particulate, gr/SCF					Particulate, gr/SCF @ 12% CO_2			
		Impinger			Percent		Impinger		
Date	Dry	Extract	H_2O	Total	CO_2	Dry	Extract	H_2O	Total
10/09/78	.0383	.00230	.00910	.0497	5.0	.0919	.00552	.0218	.119
10/10/78*	.0713	--	--	--	5.3	.2312	--	--	--
10/11/78	.0530	.00517	.0130	.0712	3.9	.163	.0159	.0400	.219
10/11/78*	.0379	--	--	--	3.9	.0968	--	--	--
10/11/78	.0195	.00680	.0237	.0500	3.7	.0632	.0221	.0769	.162
10/12/78*	.0332	--	--	--	3.9	.0949	--	--	--
10/12/78	.0404	.00200	.00912	.0516	4.0	.121	.0060	.0274	.155
10/12/78*	.0380	--	--	--	4.0	.1036	--	--	--
10/13/78*	.0517	--	--	--	3.4	.1443	--	--	--
10/13/78	.0582	.00812	.00907	.0681	3.8	.184	.00256	.0286	.215

* Alternate tests were run with peroxide solution.

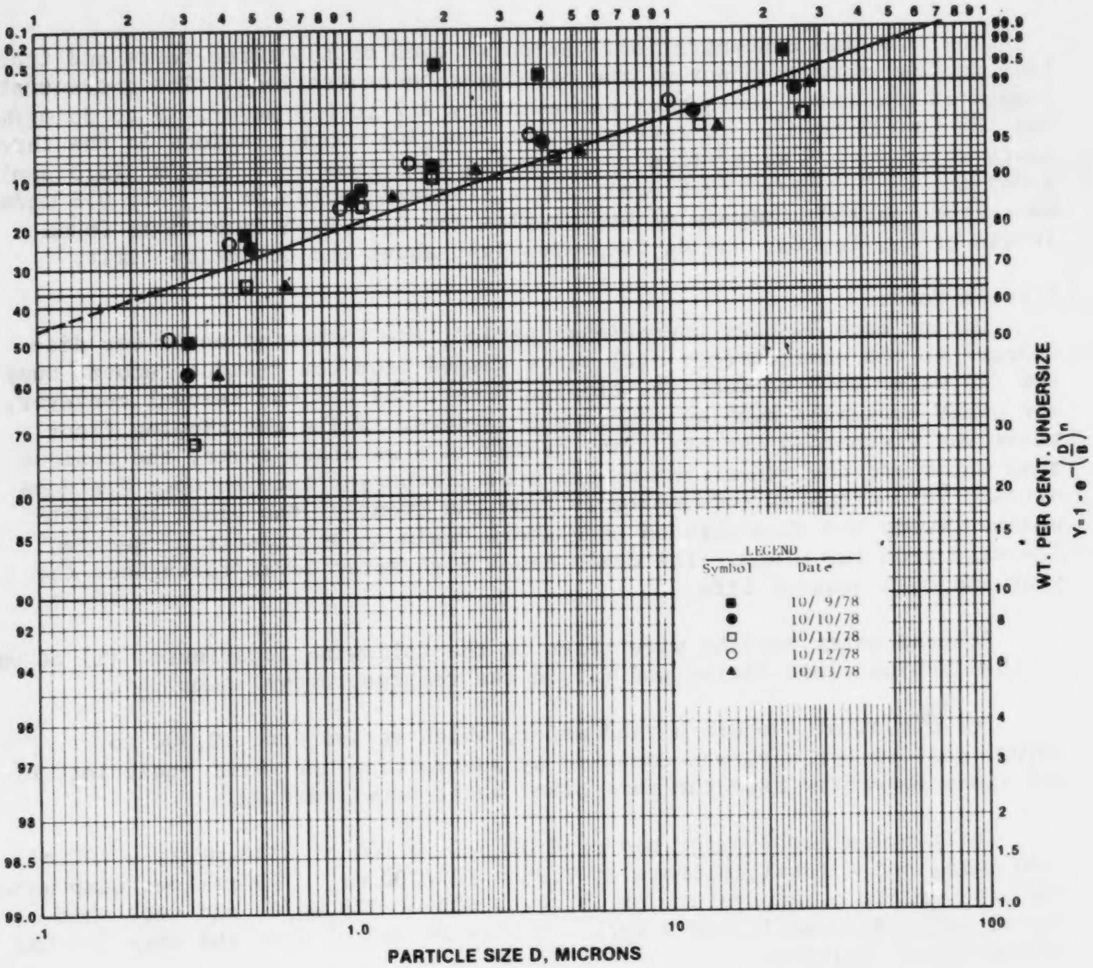


Figure 42. Particulate size distribution of stack emissions at North Little Rock facility.

The soot was blown off the boiler tubes about every 4 hours. The air, which was pressurized to 220 psi, was blown on the tubes in a top-to-bottom sequence. During this soot blowing, large aggregated particulates exited the boiler stack. The quantity and characteristics of the soot were not determined. Most of the particulates fell on the roof and within the site boundaries.

The SO_x concentrations averaged 13 mg/m^3 (5 ppm) and had a maximum of 136.6 mg/m^3 (52.2 ppm), a minimum of 3.7 mg/m^3 (1.4. ppm), and a standard deviation of 9 mg/m^3. The NO_x concentrations averaged 130 mg/m^3 (68 ppm) and had a maximum of 214 mg/m^3 (112 ppm), a minimum of 57 mg/m^3 (30 ppm), and a standard deviation of 38 mg/m^3.

The chloride concentrations varied in each of the three tests and from test to test more than any of the other gas concentrations. The concentration ranges in the three tests were successively 217 to 610 mg/m^3, 19 to 35 mg/m^3, and 128 to 193 mg/m^3. In contrast, the fluorine concentrations in the three tests averaged 1.6 mg/m^3 (2.6 ppm) and had a maximum of 4.3 mg/m^3 (5.5 ppm), a minimum of 0.5 mg/m^3 (0.6 ppm), and a standard deviation of only 0.6 mg/m^3. Gas chromotograph analysis of the samples for C_1 - C_6 hydrocarbons found levels of C_1, C_2, C_3, and C_4 compounds just above the detection limit.

Process Water—

During each 24-hour operational period, the following water was discharged to the environment: (1) water pumped from the residue removal sump and (2) water used to wash the tipping floor, the residue removal conveyor, and other equipment such as trucks and loaders. While the tipping floor water was discharged through floor drains to a sanitary sewer, the residue sump water and the other wash waters were discharged into an open drainage ditch. This ditch extends westerly from the front of the plant to a wet-weather swamp and then into an open storm drain in an industrial section 1/4 mile from the plant. The drain has a high water level throughout the year and much aquatic life.

Process water samples were taken at the following locations: (1) at one of the tipping floor drains and (2) in the residue removal sump.

The amount of the discharged water, which varied from 10,000 to 30,000 gallons per day, was computed by subtracting the water equivalent of the steam generated from the main plant water meter reading.

The tipping floor water had a pH of 5.8, a BOD of 1140 mg/ℓ, a COD of 1880 mg/ℓ, and a total coliform of 7.26×10^5/100 mℓ. The residue sump water had a pH of 12, a temperature of 39° C, a COD of 378 mg/ℓ, and settlable (total-suspended) solids of 5 mg/ℓ. Tables 24 and 25 list the data for the process water analyses.

Residue Effects on Actual Landfill--

The residue was dumped on a site (see Figure 14) that was approved by the State of Arkansas. When the site was inspected, there were many piles that evidenced about a month interim since the piles had been covered with dirt. Rain and weather had washed away the finer ash to completely expose rusting metal, glass, and clinkers. While no leachate pools were visible, much of the drainage area could not be inspected because of its being covered with flattened brush and tree debris.

The chemical analyses of the original residue samples and the simulated leachate filtrate are presented in the later discussions of the EPA Level One analysis.

TABLE 24. NORTH LITTLE ROCK WEEKLY WASH WATER POLLUTANT PARAMETER VALUES FOR MARCH, MAY, AND OCTOBER TESTS

	WASH WATER SOURCE				
Parameter	Tipping Floor			Residue Removal Equipment	Skid-Steer Loader
Date	3/22	5/25	10/10	3/21	3/23
pH		5.8	5.2	12.7	
Total solids (mg/ℓ)	362	2020	5520		362
Settable solids (mg/ℓ)	200	1070	19	5	10
Hardness $CaCO_3$ (mg/ℓ)		295			
Fecal streptococcus (10^6/100 mℓ)	.0278	.48	5.3		.016
Total coliform (10^6/100 mℓ)	.726	.75	4.7		.605
Fecal coliform (10^6/100 mℓ)	.121	.007	.300		.009
COD (mg/ℓ)	1880	2710		378	193
BOD (mg/ℓ)	1140	1780			126

TABLE 25. NORTH LITTLE ROCK TIPPING FLOOR WATER POLLUTANT PARAMETER VALUES (5/25 TEST)

Parameter	Concentration	
pH	5.8	
Acidity	0.0	mg/ℓ
Alkalinity	243.	mg/ℓ
Total dissolved solids	950.	mg/ℓ
Total suspended solids	1070.	mg/ℓ
Total solids	2020.	mg/ℓ
Total Kjeldahl nitrogen	27.6	mg/ℓ
Hardness	295.	mg/ℓ $CaCO_3$
Ammonia nitrogen	0.9	mg/ℓ
Biochemical oxygen demand	1780.	mg/ℓ
Total organic carbon	597.	mg/ℓ
Chemical oxygen demand	2710.	mg/ℓ
Boron	0.27	mg/ℓ
Bromide	15.8	mg/ℓ
Chloride	237.	mg/ℓ
Oil and grease	22.0	mg/ℓ
Phenols	0.0747	mg/ℓ
O-phosphate	0.412	mg/ℓ
Total phosphate	0.673	mg/ℓ
Total volatile solids	930.	mg/ℓ
MBAS	0.663	mg/ℓ
Sulfate	33.8	mg/ℓ
Sulfide	<1	mg/ℓ

Plant Areas--

With the respirable fraction personnel sampler attached to the skid-steer loader, the ambient air inside the plant was sampled for dust content while both the packer trucks and the loader were working the refuse, that is, dumping, mixing, and moving the refuse. A second sample was taken while only the loader was operative. The microbiological analysis of the two sets of samples revealed that the truck dumping did not appreciably increase the amount of viable organisms per cubic foot of air sampled. These analyses are summarized in Table 26. The health effects at different levels and with different types of microorganisms could not be determined because of insufficient data relating the levels to human health. Most of the microorganisms were likely attached to the dust particles. The dust concentrations ranged from 0.30 to 1.19 mg/m^3 with an average of 0.82 mg/m^3 and a standard deviation of 0.23 mg/m^3. These concentrations are detailed in Table 27.

A hand-held Ecolyzer, a carbon monoxide level indicator, was carried throughout the plant. Carbon monoxide levels in the tipping floor and in the boiler room were below the detection limit of 10 ppm even when the garbage packer trucks were dumping. The large entrance and exit doors and the boiler room doors were always open. The ventilation was good.

TABLE 26. NORTH LITTLE ROCK DAILY FUGITIVE AIR MICROBIOLOGICAL CONCENTRATIONS FOR MARCH, MAY, AND OCTOBER TESTS

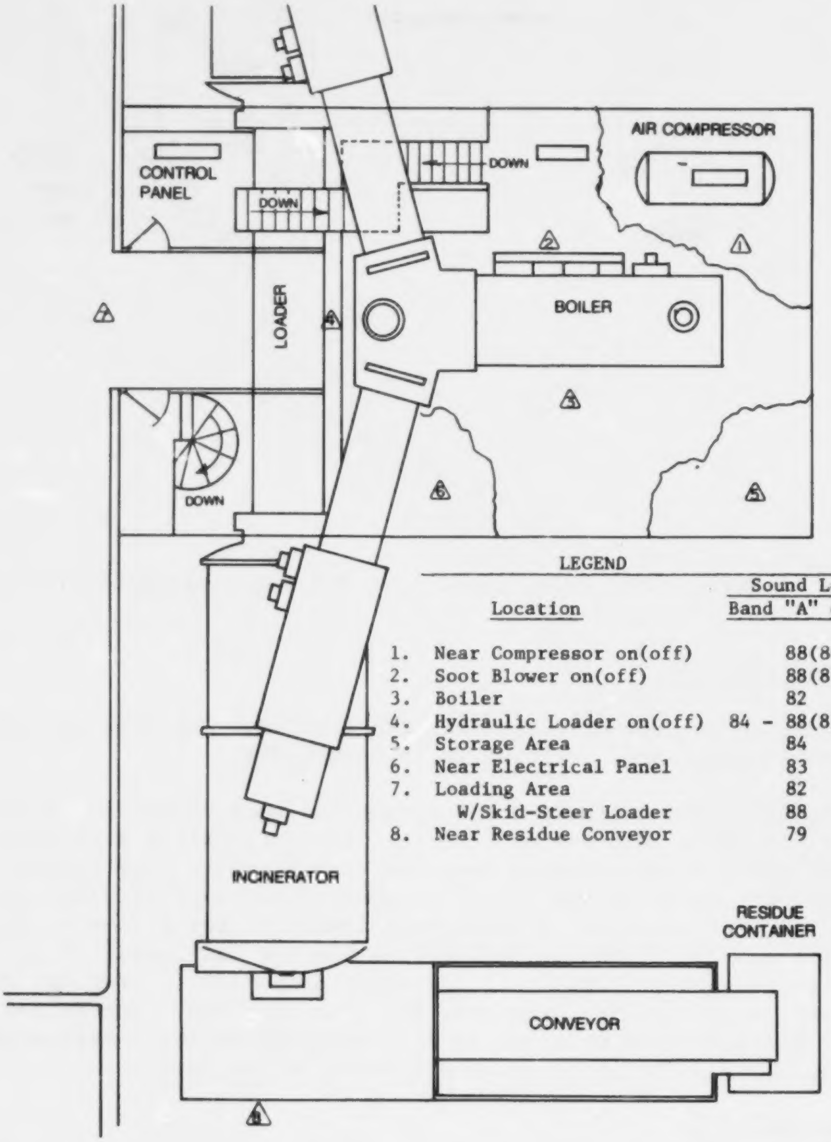
Date	Number of organisms per ft^3	Remarks
03/06	29	Average of 5 samples taken during refuse truck dumping
03/22	158	Average of 2 samples taken during refuse truck dumping
03/22	80	One sample taken while working refuse
05/23	235	One sample taken during truck dumping
05/23	360	Average of 3 samples taken while working refuse
05/25	318	Average of 2 samples during loading cycles
10/10	335	Average of 3 samples during loading cycles
10/12	188	Average of 3 samples during loading cycles

The carbon monoxide levels around the incinerators were also undetectable except for the period when the residue removal ram was cycling. During this period, the pit under the incinerator and the passageway alongside the building had carbon monoxide levels of about 50 ppm that lasted for 30 to 60 seconds. This CO level was caused by the burning chars being pulled out from the ash sump on top of the removal ram and by gases escaping around the ram when residue fell into the water.

TABLE 27. NORTH LITTLE ROCK DAILY IN-PLANT FUGITIVE DUST CONCENTRATIONS FOR MARCH, MAY, AND OCTOBER TESTS

Date	Concentration (mg/m^3)
03/6	1.19
03/21	0.98
03/22	1.06
03/23	0.89
05/22	1.11
05/23	0.68
05/24	0.66
05/25	0.55
10/10	0.74
10/13	0.30
Average	0.82
Standard Deviation σ =	0.23

As shown by the noise-level plot in Figure 43, no area in the plant had a noise level above 90 dB on the A band. The noise levels at the plant boundaries were normally between 62 and 66 dB. When a train passed by, the dB level at the boundary adjacent to the railroad tracks rose to between 75 and 80 dB, as illustrated in Figure 44.


AIR COMPRESSOR
CONTROL PANEL
DOWN
DOWN
1
2
7
LOADER
4
BOILER
3
DOWN
6
5
INCINERATOR
RESIDUE CONTAINER
CONVEYOR
8

LEGEND

	Location	Sound Level Band "A" dB	Imp
1.	Near Compressor on(off)	88(84)	105
2.	Soot Blower on(off)	88(87)	100
3.	Boiler	82	94
4.	Hydraulic Loader on(off)	84 - 88(81)	
5.	Storage Area	84	
6.	Near Electrical Panel	83	
7.	Loading Area	82	
	W/Skid-Steer Loader	88	
8.	Near Residue Conveyor	79	93

Figure 43. In-plant noise-level plot for North Little Rock facility.

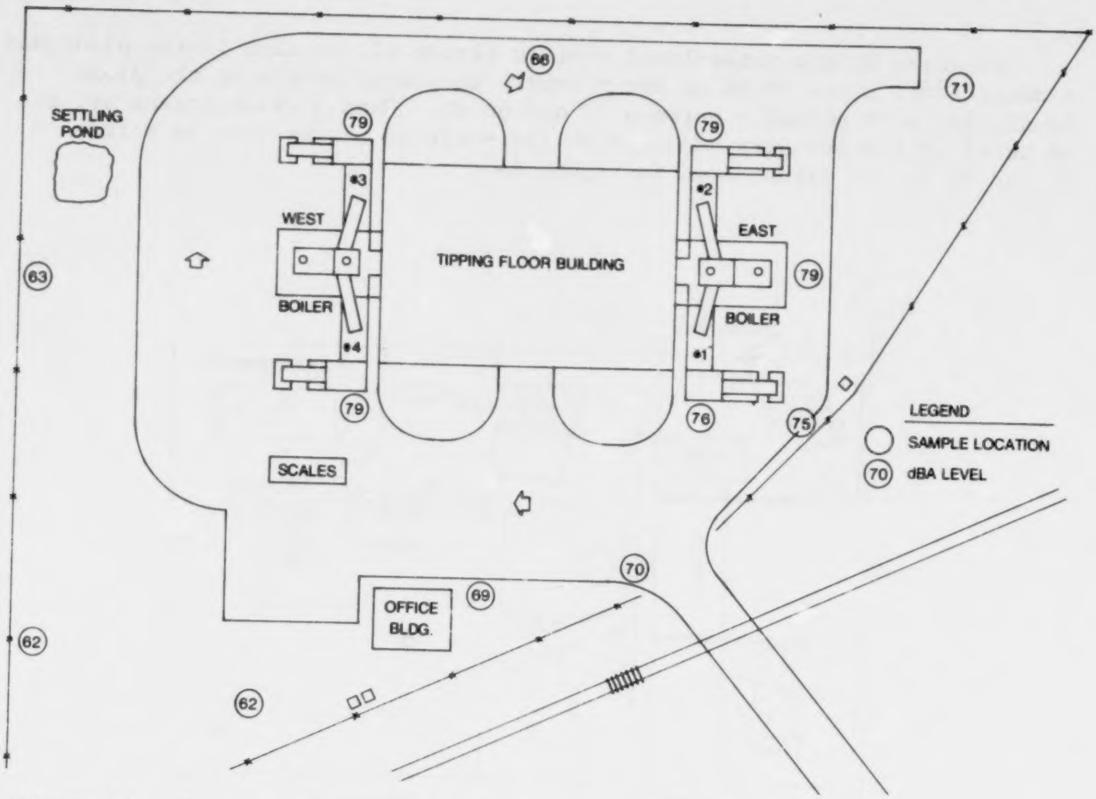

SETTLING POND
66
71
79
79
#3
#2
WEST
EAST
TIPPING FLOOR BUILDING
63
79
BOILER
BOILER
#4
#1
79
76
75
LEGEND
SAMPLE LOCATION
70
dBA LEVEL
SCALES
70
OFFICE BLDG.
69
62
62

Figure 44. Outside-plant noise-level plot for North Little Rock facility.

EPA Level One Analysis

This section briefly discusses the EPA Level One analysis and presents the significant pollutants detected in this analysis.

The EPA Level One tests were run during the week of May 22 to 26, 1978. The ambient air tests were run as follows: the particulate size distribution test was run for a 24-hour period over the 23rd and 24th, the filter for chemical analysis was installed for a 24-hour period over the 25th and 26th, the ambient sorbent trap Nos. 1 and 3 were installed for a 24-hour period over the 24th and 25th, and the Tedlar grab sampler was installed on the 23rd. The stack sorbent traps were installed as follows: trap No. 5 on the 23rd, trap No. 4 on the 24th, and trap No. 2 on the 25th. The Method 5 filter and impinger tests were run at the same time as the installation of sorbent trap No. 5. The grab sample was taken on the 24th.

Stack Emissions--

The flue gases in the boiler exhaust stack were periodically sampled and subjected to various types of analyses to reveal the organic and inorganic contaminants in the gases exiting to atmosphere.

In the gas chromatograph analysis of the filter samples for organic contaminants, no C_7 - C_{12} hydrocarbons, chlorinated hydrocarbons, or organic sulfur compounds were detected. However, in the analysis for inorganic contaminants, arsenic and mercury were detected. Moreover, spark source mass spectrometry analysis found detectable levels of lead, tin, copper, zinc, nickel, phosphorus, and sulfur.

When the impinger solutions were tested for arsenic, antimony, and mercury, none of these contaminants were detected. However, further tests of these solutions detected boron, chlorine, iron, copper, manganese, sulfur, and the halogens chlorine, benzine, and iodine.

In the gas chromatograph analysis of the resin in the sorbent trap, no chlorinated or sulfur compounds were detected. Octane (C_8) and dodecane (C_{12}) vapors were detected in only one sample. However, liquid chromatography and infrared analysis detected heavy hydrocarbons, most probably esters of a high molecular weight organic acid. In addition, atomic absorption analysis detected arsenic, antimony, and mercury. Moreover, spark source mass spectrometry analysis found detectable levels of chromium, copper, zinc, lead, iron, and chlorine.

The Tedlar bag samples were analyzed for hydrogen sulfide (H_2S) and carbonyl (COS) sulfide by spark source mass spectrometry. With detection levels of 10 ppm for H_2S and 25 ppm for COS, neither of the sulfides were found.

Process Water--

Samples of the tipping floor wash water were divided into liquid and solid fractions. In the tests for organic contaminants and chlorinated hydrocarbons, only the liquid fraction was analyzed because of the known organic content of the solid fraction. No contaminants were detected in these tests. In the tests for inorganic contaminants, both fractions had detectable arsenic and mercury, but the levels in the liquid fraction were much higher than those in the solid fraction. Samples of the tipping floor wash water were also tested for total coliform and fecal streptococcus counts. Table 28 summarizes the results.

TABLE 28. NORTH LITTLE ROCK TIPPING FLOOR WATER MICROBIOLOGICAL CONCENTRATIONS FOR MARCH, MAY, AND OCTOBER TESTS

	Colony Concentration per 100 ml		
Date	Total Coliform	Fecal Coliform	Fecal Streptococcus
03/22	726,000	121,000	27,800
03/23*	605,000	8,600	15,900
05/25	750,000	7,000	480,000
10/10	4,700,000	300,000	5,300,000

* Wash water from skid-steer loader included.

Residue and Leachate--

In the gas chromatography analysis of the residue samples for chlorinated hydrocarbons and sulfur compounds, none of these contaminants were detected. However, in the gas chromatograph analysis for C_7 - C_{12} hydrocarbons, the test found 63.0 μg/m^3 of decane (C_{10}) and 19.0 μg/m^3 of undecane (C_{11}). In addition, the atomic absorption analysis found 1.96 μg/m^3 of arsenic and 6.20 μg/m^3 of antimony; the infrared analysis detected a functional group of a medium C-H stretch; and the spark source mass spectrometry analysis detected many elements in high concentration, the most significant being lead with 5000 μg/g, tin and chromium each with 1000 μg/g, and phosphorus and iron each with more than 1000 μg/g. The significant results are summarized in Table 29.

TABLE 29. NORTH LITTLE ROCK RESIDUE COMPONENT CONCENTRATIONS

Component	Concentration μg/g
Decane	63.0
Undecane	19.0
Arsenic	1.96
Antimony	6.20
Sulfur	1000
Chlorine	100
Potassium	High*
Phosphorus	High
Chromium	1000
Iron	High
Zinc	High
Copper	500
Fluorine	0
Tin	1000
Molybdenum	0
Barium	500
Lead	5000
Cadmium	High
Bromide	0
Boron	100
Mercury	0

* High > 1000

In the chemical analysis of the leachate filtrate from the run with only distilled water with a 5.5 pH, the pH, hardness, alkalinity dissolved solids, and the chloride, sulfate, fluoride, and antimony concentrations increased. In the analysis of the filtrate from the run with both distilled water and a phosphate buffer to lower the pH to 5.0, the pH, alkalinity, dissolved solids, and the chloride, sulfate, and bromide concentrations also increased. However, in the filtrate of the latter run, the pH increase was less and the alkalinity and dissolved solid increases were more than those in the filtrate of the former run. The phosphate buffer did interfere with the ortho and total phosphate test. The results are presented in Table 30.

TABLE 30. NORTH LITTLE ROCK RESIDUE LEACHATE PARAMETER AND COMPONENT VALUES

		Water Blank	Test 1	Phosphate Buffer Test 2
pH		5.52	8.65	6.05
Conductivity	umhos	2.78	185.00	2800
Alkalinity	mg/ℓ	1.10	43.50	144
TKN	mg/ℓ	6.95	5.25	11.6
Hardness	mg/ℓ	2.00	70.00	ND
TOC	mg/ℓ	3.10	5.70	2.2
Ortho-Phosphate	mg/ℓ	0.005	0.025	1400
Total Phosphate	mg/ℓ	0.01	0.044	1975
Sulfide	mg/ℓ	<0.002	0.002	ND
Chloride	mg/ℓ	ND	0.71	12
Acidity	mg/ℓ	5	ND	1841
Total Dissolved Solids	mg/ℓ	<1	80	5770
Ammonia as N	mg/ℓ	0.216	0.183	0.23
COD		ND	ND	ND
Sulfate	mg/ℓ	<1.00	34.30	16.6
Bromide	mg/ℓ	<0.100	<0.100	1.0
Fluoride	mg/ℓ	0.058	0.099	.07
Boron	mg/ℓ	<0.1	<0.1	127
Mercury	μg/ℓ	<0.1	<0.1	-
Cadmium	μg/ℓ	<1	<1	-
Antimony	μg/ℓ	<1.0	5.4	-
Lead	μg/ℓ	<1	<1	-
Chromium	μg/ℓ	<1	<1	-
Arsenic	μg/ℓ	ND	ND	-
Cyanide	mg/ℓ	-	-	.002
Phenols	mg/ℓ	-	-	.005
MBAS	mg/ℓ	-	-	0.12

ND None detected.

Outside Ambient Air--

The ambient air outside the plant was sampled upwind and downwind by the high-volume sampler, the sorbent trap enclosed in a weatherproof box, and the Tedlar bags. With the prevailing wind given by the Little Rock airport, the upwind sample site was positioned outside the plant boundary in a wet-weather swamp some 100 meters from the plant. The downward sample site was located a like distance away but within the plant boundary adjacent to the Koppers' plant.

The chemical analysis of the filters in the high-volume sampler detected no heavy hydrocarbons, chlorinated hydrocarbons, sulfur compounds, mercury, arsenic, or antimony. In addition, the spark source mass spectrometry analysis detected no inorganic elements. Table 31 lists the weights of the particulates captured on each of the three stages of the Anderson head impactor.

While the gas chromatograph analysis of the resin in the sorbent trap also did not detect any heavy hydrocarbons, chlorinated hydrocarbons, or sulfur compounds, the spark source mass spectrometry analysis found some traces of inorganic elements.

The Tedlar bag samples were analyzed for carbonyl, hydrogen sulfide, organic sulfur compounds, ammonia, prussic acid, and cyanide with none being detected.

TABLE 31. NORTH LITTLE ROCK AMBIENT AIR PARTICULATE SIZE DISTRIBUTIONS

UPWIND

Particle Size μ	Weight gm	Concentration μg/m^3
>7	0.0234	28.7
1.1 - 7	0.0179	22.0
<1.1	0.0228	28.0
TOTAL		78.7

DOWNWIND

Particle Size μ	Weight gm	Concentration μg/m^3
>7	0.0362	44.4
1.1 - 7	0.0302	37.0
<1.1	0.0355	43.5
TOTAL		125.9

Summary--

Of the major pollutants detected in the EPA Level One analysis, antimony, arsenic, lead, and mercury were consistently found in small amounts. Other metals and heavy organics were found occasionally in smaller amounts. Table 32 summarizes the air emissions findings, and Table 33 quantifies the high values found in the emissions filters as given in Table 32.

The contaminates were found in the stack emission, the tipping floor wash water, the residue, and the water that came in contact with the residue.

TABLE 32. NORTH LITTLE ROCK SUMMARY OF ELEMENTS DETECTED IN EPA LEVEL ONE ANALYSIS

	Element Source									
	Ambient Air				Stack Emissions					
	Filter		Sorbent Trap		Sorbent Trap			Method 5 Filter	Method 5 Impingers	
Element	Upwind	Downwind	Upwind	Downwind	2	4	5		1	2 & 3
Li	N	D	D	D	D	D	D	N	N	D
Be	N	N	N	N	N	N	N	N	N	N
B	D	D	D	D	D	D	D	D	D	D
F	D	D	D	D	N	N	N	D	N	N
Na	D	D	D	D	D	D	D	D	D	D
Mg	D	D	D	D	D	D	D	D	D	D
Al	D	D	D	D	D	D	D	D	D	D
Si	D	D	D	D	D	D	D	D	D	D
P	D	D	D	D	D	D	D	D	D	D
S	D	D	D	D	D	D	D	D	D	D
Cl	D	D	N	N	N	N	D	D	D	D
K	D	D	D	D	D	D	D	D	D	D
Ca	D	D	D	D	D	D	D	D	D	D
Sc	N	N	N	N	N	N	N	N	N	N
Tu	D	D	N	N	D	D	D	D	D	D
U	N	N	N	N	N	N	N	N	N	N
Cr	D	D	N	N	D	D	D	N	N	N
Mn	D	D	N	N	D	D	D	D	D	D
Fe	D	D	D	D	D	D	D	D	D	D
Co	N	N	N	D	N	N	N	D	N	N
Ni	N	N	N	D	N	N	N	D	N	N
Cu	D	D	D	D	D	D	D	D	D	D
Zn	D	D	D	D	D	D	D	D	D	D
Ga	N	N	N	N	N	N	N	D	N	N
Ge	N	N	N	N	N	N	N	N	N	N
Se	N	N	N	N	N	N	N	N	N	N
Br	N	N	N	N	N	N	N	N	N	D
Rb	N	N	N	N	N	N	N	D	N	N
Ag	N	N	N	N	N	N	N	D	D	*
Sn	N	N	N	N	N	N	N	D	N	N
Cs	-	-	N	N	N	N	N	D.	N	N
Pb	D	D	N	N	N	D	N	D	N	N
Bi	N	N	N	N	N	N	N	D	N	N
I	N	N	N	N	N	N	N	N	N	D
As	N	N	N	N	N	D	D	D	N	N
Sb	N	N	N	N	D	N	N	N	N	N
Hg	N	N	D	N	D	D	D	D	N	N
NH_3	-	-	-	-	-	-	-	-	D	N
HCN	-	-	-	-	-	-	-	-	N	N
CH_2O	-	-	-	-	-	-	-	-	D	D

N Not Detected D Detected
* Test interference - No test
33 other elements tested for were not detected.

TABLE 33. NORTH LITTLE ROCK SUMMARY OF ELEMENTS DETECTED IN STACK EMISSION FILTERS

Element	Emission rate Concentration in gas ($\mu g/m^3$)*	Emission factor g/Mg of refuse†
Silicon	3.22	.0505
Iron	261.	4.10
Aluminum	331.	5.20
Sodium	9,363.	147.0
Calcium	894.	14.0
Potassium	381.	5.98
Magnesium	331.	5.20
Lead	4,280.	67.2
Zinc	9,071.	142.
Cadmium	123.	1.93
Beryllium	0.114	.0018
Titanium	.333	.0052
Chromium	1.105	.0173
Copper	62.57	.982
Nickel	1.97	.031
Manganese	8.02	.126
Lithium	2.48	.039
Antimony	13.26	.208
Boron	105.0	1.640
Tin	3.81	.0598
Vanadium	2.26	.0354

* Concentrations based on a composite of six filters from October test period.

† g/Mg ÷ 500 = lb/ton

The tipping floor water is treated by a municipal treatment plant. Concentrations of the pollutants are not high enough to affect the treatment plant's operation. Many trace elements were found in small amounts, with the small particulate size (<7μm) emissions common to small modular incinerator operation. The residue could also become a pollutant by its surface drainage at the local site and by its leachate formation at the disposal site.

Economic Evaluation

Accounting System--

The City's accounting system is organized and operated on a fund basis and is typical of that found in a municipal environment. In the accounting sense, a fund is defined as an independent fiscal and accounting entity with a self-balancing set of accounts in which all financial activities related to specific objectives are segregated and recorded. The segregation and recording of financial activities for specific objectives are performed according to special regulations, restrictions, or limitations.

The City maintains several funds within its accounting structure. Funds which specifically relate to the construction and maintenance of the solid waste plant include (1) the general fund which is used primarily to account for the expenditures of general government, (2) special revenue funds which are used to account for particular revenues such as Federal revenue sharing and grant funds and funds assigned for specific purposes, and (3) capital project funds which are funds allocated for the construction of various facilities.

All plant operating and maintenance costs are recorded and accounted for in the general fund, while plant capital expenditures are recorded in the 1971 and 1976 Sanitation Funds (which are capital project funds). A special revenue fund was also established to account for the plant steam revenues and to retire plant principal and interest payments for construction.

The City of North Little Rock accounting records are prepared or maintained on a cash basis of accounting. Under the cash basis no adjustments are made for prepaid, unearned, and accrued items. Revenues in cash are reported as being earned in the accounting period in which they are received, and expenses are deducted from revenues in the accounting period in which cash is disbursed for their payment. As a result, operating and maintenance costs or steam revenues recorded during a given time period may not represent actual incurred costs or revenues of that period but rather may cover expenses and income attributed to other time periods.

The City of North Little Rock maintains a chart of accounts for the general fund. This chart permits identifying operating and maintenance costs in the following classifications: (1) personnel services, (2) salaries, (3) overtime wages, (4) holiday pay, (5) FICA, (6) employee benefits, (7) employee retirement pension, (8) maintenance, (9) utilities and communication, and (10) gasoline and oil.

The City anticipates that additional cost classifications will be added as it becomes more experienced in the plant operation.

Because of the City's cash basis of accounting, the plant's revenues and operating expenses cannot be properly correlated with time periods. Accordingly, to make the costs more representative of the time periods, the project team maintained independent records of all operating and maintenance costs on an accrual basis of accounting.

Capital Costs and Their Financing--

The capital costs expended on the incinerator plant were identified by examining the City's accounting records and related contractual agreements and by interviewing City personnel.

All recorded capital expenditures related to the incinerator plant were charged to the capital project funds accounts (the 1971 and 1976 Sanitation Funds). From these accounts, vouchers covering the recorded expenditures were identified. Source documents relating to the vouchers were reviewed to determine whether the expenditures were (1) properly chargeable to the project, (2) properly classified as capital expenditures, (3) materially accurate for reclassification per EPA guidelines and cost centers, and (4) in need of adjustment according to supporting documentation examination.

This review revealed that $1,454,846 for the plant construction was charged to the capital project funds but that an additional $64,558 ($43,158 for site preparation and $21,400 for plant design) was not formally charged to these funds. In addition, while two acres of land for the plant site were donated and are leased at a nominal cost, an estimated land value of $10,000 was added to the capital cost to make the total cost more realistic. The total capital cost, therefore, was $1,529,404. Table 34 presents the total capital cost breakdown which generally agrees with the EPA cost categories.

TABLE 34. NORTH LITTLE ROCK ACTUAL CAPITAL COSTS*

Land	$ 10,000
Site preparation	101,093
Design	37,583
Construction	311,383
Real equipment	968,929
Other equipment	62,886
Other costs	37,530
Total capital investment	$1,529,404

*Based on actual costs in 1977.

After the incurred costs as specified in the contract requirements and as evidenced in the documents for supporting items were reviewed, the total capital cost was distributed among four cost centers: the three functional areas, namely receiving, incineration, and heat recovery, and the general plant. In addition to the distribution among the four cost centers, Table 35 presents a distribution of the total capital cost among the three functional areas. The latter distribution was prepared by allocating to each functional area that part of the $126,020 for the general plant which was in proportion to its amount in the first distribution. The reason for the second distribution was that the general plant cost covers miscellaneous depreciable items that are applicable to the functional areas.

TABLE 35. NORTH LITTLE ROCK CAPITAL COST ALLOCATIONS BY COST CENTER

Cost center	Capital cost	Reallocated capital cost
Receiving	$ 245,650	$ 267,709
Incineration	789,690	860,602
Heat recovery	368,044	401,093
General plant	126,020	
Total	$1,529,404	$1,529,404

Then for each depreciable item, Table 36 lists the initial cost, including as applicable the freight, insurance, and installation costs; the related cost center; and the estimated useful life. The estimated useful lives, namely 15 to 20 years for real equipment items and generally 20 years for the other items, were used in computing the annual depreciation expenses which are presented under the operating and maintenance costs.

Although the actual total capital cost of the facility was $1,519,404, $64,559 (as discussed above) was allocated for the facility but not formally charged to the capital project funds and $103,846 was acquired as a trade-in allowance for previously used incinerators. Consequently, $1,351,000 was acquired by a 20-year bond issue with interest rates ranging from 5.75 to 6.75 percent. Semiannual unadjusted interest payments over the life of the bond issue will equal $1,287,194.

Operating and Maintenance Costs--

Preparatory to distributing the annual operating and maintenance costs among the four cost centers, SYSTECH provided data for the operating parameters that affect these costs. Based on the facility monitoring between September 1 and 26 of 1978, the first period of normal plant operation, the parameter data were extrapolated to represent a 24-hour day, 250-day year operation. Then the annual parameter data were distributed among the four cost centers as shown in Table 37.

Table 38 presents the unit cost data which was used in conjunction with the operating parameter data in Table 37 to arrive at the estimated operating costs. These unit costs are based on averages of the actual unit costs over the evaluation period.

The preparation of the projected operating cost required estimating the maintenance costs and including the interest and depreciation costs to make the evaluation complete and reasonable.

TABLE 36. COST, COST CENTERS, AND ESTIMATED USEFUL LIFE FOR EACH MAJOR EQUIPMENT ITEM IN NORTH LITTLE ROCK FACILITY

Equipment Item	Cost	Cost Center	Estimated Useful Life (Yrs)
4 Incinerator Units (includes pressure regulators and additional connection pedestals	$ 532,651	Incineration	15 - 20
4 Ash Conveyor Systems	72,536	Incineration	15 - 20
2 Energy Recovery Systems	195,492	Heat Recovery	15 - 20
2 Steel Platforms railings, ladder, stairs, etc	37,708	40% Heat Recovery 60% Incineration	15 - 20
Auxiliary Boiler (includes oil system, vent stack, exhaust fan)	48,005	Heat Recovery	20 - 30
4 Dual Fuel Systems	21,587	Incineration	15 - 20
High Pressure Steam Cleaner	7,088	Heat Recovery	15 - 20
Truck Scale	19,801	Receiving	20
Steam Flow Meter	4,130	Heat Recovery	15 - 20
Timber Piles	11,380	General Plant	20
Air Pollution Control	5,132	Incineration	15 - 20
Office Building	20,107	General Plant	20
Plant Shell	279,896	65% Receiving 17 1/2% Incinerator 17 1/2% Heat Recovery	20
3 Loaders	27,540	Receiving	15 - 20
Blowdown Installation Heating	24,799	Heat Recovery	15 - 20
Ash Removal Truck	25,137	Incineration	15 - 20
5 Metal Containers	8,472	Incineration	15 - 20
Design Costs Identified	37,583	General Plant	20
Miscellaneous Depreciable Costs Not Itemized	39,267	General Plant	15 - 20
Total	$1,418,311		

TABLE 37. NORTH LITTLE ROCK OPERATING PARAMETER VALUES FOR COST CENTERS

Parameter	Total	Cost Center			
		Receiving	Incineration	Heat recovery	General
Operating schedule:	24 hrs/day 250 days/year				
Refuse feed rate (75% of capacity):					
Mg/hr	2.7				
Mg/yr	16,200				
Steam production operating average (kg/hr):	4,458				
Personnel:					
Director of sanitation	0.5				0.5
Plant superintendent	1.0				1.0
Maintenance superintendent	1.0				1.0
Operator	6.0	2.4	3.0	.6	
Secretary	1.0	0.3			0.7
Truck driver	1.0		1.0		
Overtime	1.0	0.4	0.5	0.1	
Fuel consumption:					
Natural gas (ℓ/hr)	49,714		49,714		
Diesel fuel (ℓ/day)	113.3	113.3			
Gasoline (ℓ/day)	83.3		83.3		
Electric power consumption (kwh/hr):	94.3	3.4	45.8	40.0	5.1
Water consumption (ℓ/day):	278,943		11,236	89,511	178,196
Chemicals ($/yr):	3,400			3,400	
Phone ($/yr):					971
Insurance ($/yr):	2,238			1,050	1,188
Tipping fees:					
$/week	468				
$/yr	24,336				

TABLE 38. NORTH LITTLE ROCK ACTUAL ANNUAL OPERATING AND MAINTENANCE COSTS FOR COST CENTERS

Cost Classification	Total Cost	Receiving	Incineration	Heat recovery	General plant
Salaries	$111,284	$27,048	$ 38,912	$ 6,165	$ 39,159
Employee benefits	15,750	3,744	5,244	870	5,892
Fuel - No.2 Diesel	3,456	3,456			
-Natural Gas	16,704		16,704		
-Gasoline	2,916		2,916		
Electricity	19,237	693	9,349	8,157	1,038
Water and sewer	6,402		258	2,054	4,090
Maintenance	65,656	10,614	34,123	15,904	5,015
Residue Removal					
Chemicals	3,400			3,400	
Interest	44,050				44,050
Depreciation	78,070	11,661	41,771	18,940	5,698
Other overhead	3,209			1,050	2,159
Sub total	$370,134	57,216	149,277	56,540	107,101
General Plant Allocations		22,237	58,018	21,975	
Grand Total	$370,134	$79,453	$207,295	$78,515	

During the monitoring period, the plant was under warranty by the builder who performed all maintenance, much of which was developmental modifications. Therefore, since the actual maintenance costs could not be determined, estimated costs were derived by applying the Internal Revenue Service guideline for maintenance costs, namely 5.5 percent of the total depreciable assets, to the $1,418,311 given in Table 36. Although a survey of existing small modular incinerator plants revealed that their maintenance costs ranged from 2 to 3 percent of the total depreciable assets, the 5.5 percent is reasonable since the estimated costs include maintenance labor and reasonably anticipate higher maintenance expenses as the facility gets older. However, since the salary of the maintenance supervisor was included with the other salaries and the employee benefits, it was excluded from the maintenance costs.

In addition to the bond issue, the computation to determine the total annual interest included the estimated $10,000 value of the donated land and the $64,558 allocated by the City for the plant construction but not formally charged to the capital project funds. In this computation, the present net values of all interest payments were totaled and the sum was averaged over the 20-year life of the bond issue. The resultant total annual interest was $44,050 ($39,179 for the $1,351,000 bond issue and $4,872 for both the $64,558 City's cash outlay and the $10,000 land value).

In the computation of the annual depreciation cost of the items listed in Table 36, a straight line depreciation was used with 17.5 years as the life for the real equipment items and 20 years as the life for all other items.

Then the annual costs for maintenance, interest, and depreciation, as computed above, were combined with the data in Tables 37 and 38 to derive the projected annual operating and maintenance costs. Table 39 lists the resultant costs. As seen in that table, the total annual costs are $365,263 or $22.55 per Mg of refuse processed. Except for interest and depreciation, the cost categories in Table 39 generally agree with those in the EPA accounting format.

TABLE 39. NORTH LITTLE ROCK PROJECTED OPERATING AND MAINTENANCE COSTS*

Item	Cost ($/yr)	Cost ($/Mg)
Salaries	$111,284	$ 6.87
Employee benefits	15,750	0.97
Fuel - no. 2 diesel	3,456	0.21
Natural gas	16,704	1.03
Gasoline	2,916	0.18
Electricity	19,237	1.19
Water and sewer	6,402	0.40
Maintenance	65,656	4.05
Replacement equipment	--	--
Residue removal	†	†
Chemicals	3,400	0.21
Interest	39,179	2.42
Depreciation	78,070	4.82
Other overhead	3,209	0.20
Total operating and maintenance costs	$365,263	$22.55

* Based on costs incurred during September 1978.

† Cost included in salaries and employee benefit categories.

Next, in Table 40, the annual costs in Table 39 were distributed among the four cost centers according to the cost center allocations in Table 37. As noted in Table 39, the residue removal costs in Table 40 were also included in the salaries and employee benefit categories. Similarly as in Table 39, the other overhead category in Table 40 includes telephone, insurance, and other miscellaneous costs.

TABLE 40. NORTH LITTLE ROCK UNIT COST DATA*

Annual salary rates:	
Director of sanitation	$19,000
Plant superintendent	13,290
Maintenance superintendent	10,800
Operator	9,442
Truck driver	8,086
Secretary	7,956
Overtime	5,000
Employee benefits:	
Health insurance (each employee)	$29.70/month
Retirement	5.00%
FICA	6.05%
Fuel rates:	
Natural gas	$0.056/1000 ℓ
Number 2 diesel oil	$0.122/ℓ
Gasoline	$0.140/ℓ
Electricity:	$0.034/kwh
Water and sewer:	$0.0918/1000 ℓ

*Based on cost projections from costs incurred during September 1978.

As shown in Table 41, the annual costs in Table 39 were also broken down into fixed and variable costs. The rationale for the breakdown was as follows: Whenever the plant may be shut down, some salaries and employee benefits, such as those for the sanitation director, plant superintendent, and maintenance superintendent, will continue and therefore are fixed, while those for the other employees will be modified and therefore are variable. Obviously, the costs for fuel, electricity, water and sewer, and chemicals will be minimal during plant shutdowns. Therefore they were all considered variable. Regardless of the plant operation, some maintenance must be performed periodically; therefore, 50 percent of the maintenance cost was considered fixed. Since most of the costs in the other overhead category will continue during plant shutdowns, 70 percent of these costs were considered fixed. Obviously, interest and depreciation are pure fixed costs since they will continue until the corresponding assets have been fully depreciated.

TABLE 41. NORTH LITTLE ROCK ANNUAL FIXED AND VARIABLE OPERATING AND MAINTENANCE COSTS

Item	Total	Fixed	Variable
Salaries	$ 111,284	$ 33,590	$ 77,694†
Employee benefits	15,750	4,741	11,009†
Fuel - No. 2 diesel	3,456		3,456#
- Natural gas	16,704		16,704#
- Gasoline	2,916		2,916#
Electricity	19,237		19,237#
Water and sewer	6,402		6,402#
Maintenance	65,656	32,828	32,828
Replacement equipment			
Residue removal			
Chemicals	3,400		3,400
Interest	39,179	39,179	
Depreciation	78,070	78,070	
Other overhead	3,209	2,238	971
Total costs	$ 365,263	$ 190,646	$ 174,617

* Based on 1978 dollars.

† Assumes that salaries of Sanitation Director, Plant Superintendent, and Maintenance Superintendent are incurred if the plant is not operating.

# A minimal amount of these expenses would be incurred even if plant was not operating.

Revenues--

Table 42 presents the estimated annual revenues based on the September operation conditions.

Net Operating Costs--

With $365,263 as the projected annual operating and maintenance cost and $177,335 as the estimated annual revenue, the net annual operating cost will be $187,928. Table 43 presents the costs, revenues, and net costs per unit of refuse processed.

Summary--

With the facility requiring an initial capital investment of $1,529,404, its anticipated annual operation will cost $187,928 or $11.67 per Mg ($10.53 per ton) of refuse processed.

During the evaluation period, the net operating cost approached the alternative landfill cost of $4.86 per Mg ($4.41 per ton) of refuse processed partly because of increasing efficiency but mostly because the builder defrayed the maintenance costs under the warranty and the salaries of 3 of the 11 employees were paid through a Federal program. Nevertheless, the projected net annual operating cost remains $11.67 per Mg ($10.53 per ton) of refuse processed.

TABLE 42. NORTH LITTLE ROCK PROJECTED ANNUAL REVENUES*

Sources	Revenue
Steam production	$152,999
Commercial dumping fees	24,336
Total	$177,335
Per Mg of refuse processed (per ton)	$10.94 (9.92)

* Based on 1978 dollars.

TABLE 43. NORTH LITTLE ROCK PROJECTED ANNUAL NET OPERATING COSTS*

	Cost	
	($/Mg)	($/ton)
Operating and maintenance costs	(22.55)	(20.45)
Revenue	10.94	9.92
Net cost of operation (tipping fee)	(11.67)	(10.53)

* Based on costs incurred during September 1978.

MARYSVILLE FACILITY

Description

General--

This facility is located at the Truck Axle Division of the Rockwell International Corporation in Marysville, Ohio (see Figure 45). Since most of the division's energy supply is propane gas, the natural gas shortage in the winter of 1976-77 prompted the decision to install a solid waste incinerator system with heat recovery. The system was intended for the twofold purpose of burning the division's solid waste, mostly packing and shipping scraps, and of providing energy for both heating and cooling the main building by recovering the combustion gas heat in the form of hot water.

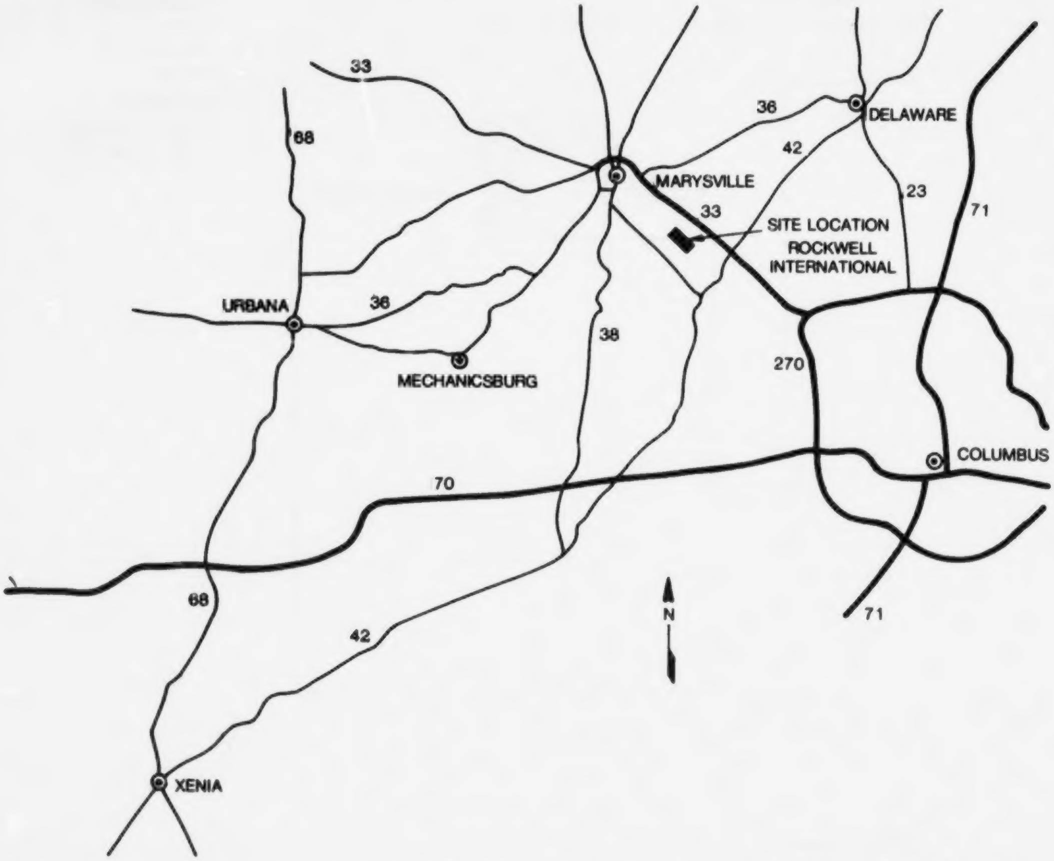

33
68
36
42
DELAWARE
MARYSVILLE
33
23
71
SITE LOCATION
ROCKWELL
INTERNATIONAL
URBANA
36
38
MECHANICSBURG
270
COLUMBUS
70
68
42
N
71
XENIA

Figure 45. Vicinity map of Marysville (Rockwell International) facility.

To accommodate the waste-to-heat facility, a 9m (30-ft) × 15m (50-ft) structure was added alongside the assembly area of the main building. This structure consists of prefabricated steel walls with an integral roof and a concrete floor. The waste-to-energy system includes a Kelley Model 1280 incinerator with a Kelley Model 72 feeder, a York-Shipley Series 565 firetube boiler, and a Trane absorption chiller. Figures 46 and 47 show the layout and a cross section of the system, respectively. Both the primary and secondary chambers of the incinerator are outside the facility housing so that the main building is remote from excessive heat radiating from the incinerator.

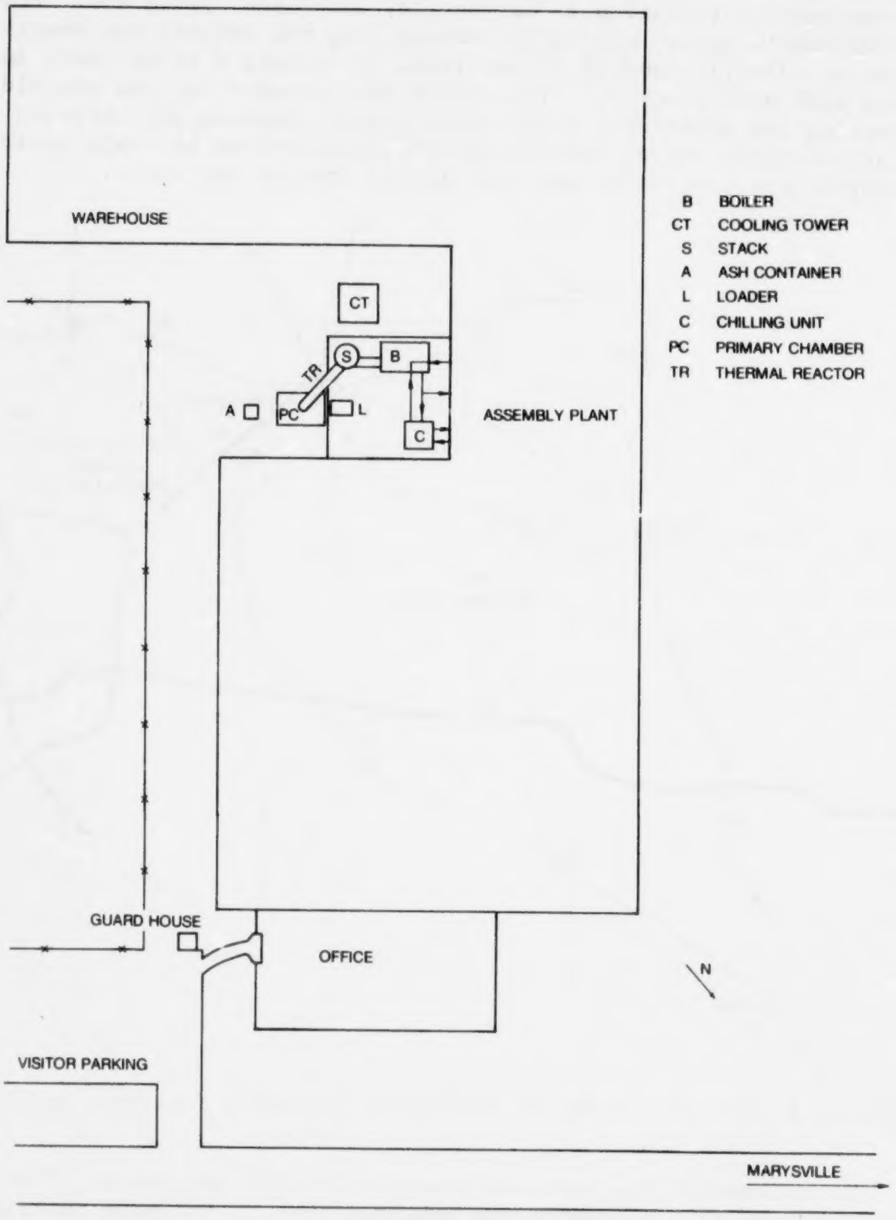

WAREHOUSE
CT
S
B
TR
A
PC
L
C
ASSEMBLY PLANT
GUARD HOUSE
OFFICE
VISITOR PARKING
MARYSVILLE
N
B BOILER
CT COOLING TOWER
S STACK
A ASH CONTAINER
L LOADER
C CHILLING UNIT
PC PRIMARY CHAMBER
TR THERMAL REACTOR

Figure 46. Plant layout of Marysville facility.

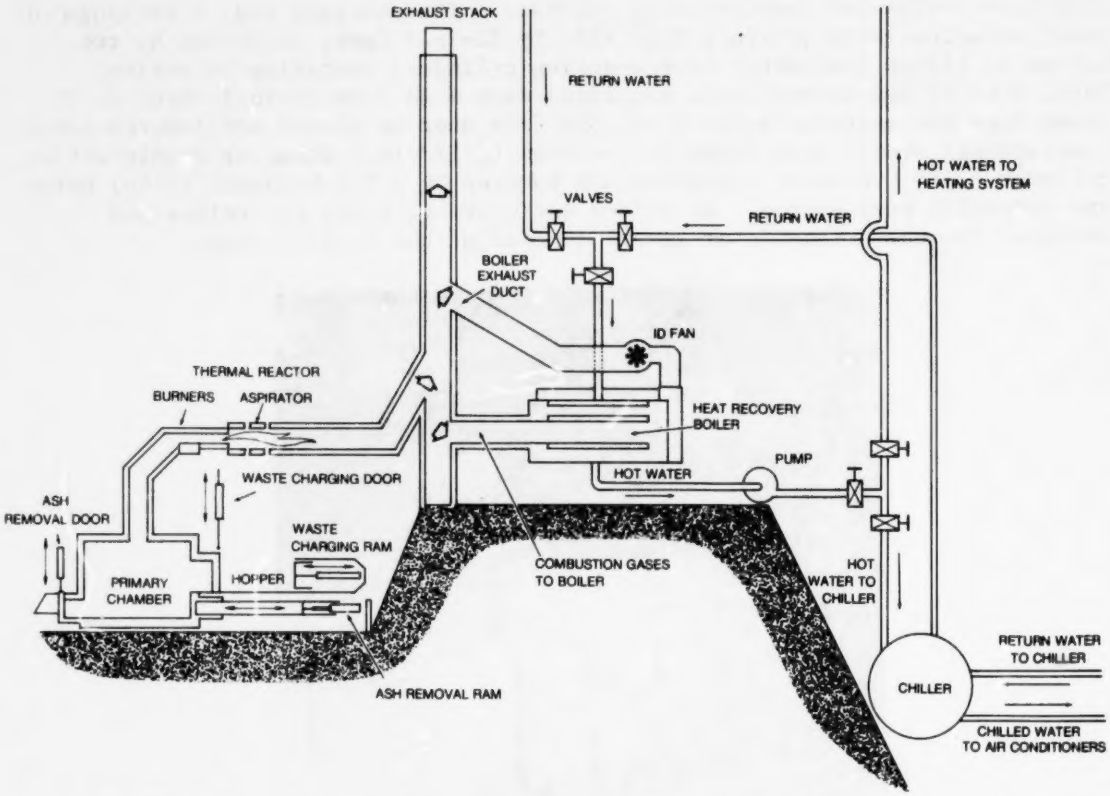

EXHAUST STACK
RETURN WATER
HOT WATER TO HEATING SYSTEM
VALVES
RETURN WATER
BOILER EXHAUST DUCT
ID FAN
THERMAL REACTOR
BURNERS
ASPIRATOR
HEAT RECOVERY BOILER
PUMP
HOT WATER
WASTE CHARGING DOOR
ASH REMOVAL DOOR
WASTE CHARGING RAM
PRIMARY CHAMBER
HOPPER
COMBUSTION GASES TO BOILER
HOT WATER TO CHILLER
RETURN WATER TO CHILLER
CHILLER
CHILLED WATER TO AIR CONDITIONERS
ASH REMOVAL RAM

Figure 47. Functional schematic of incineration-heat recovery processes in Marysville facility.

While the refuse is burned 16 hours a day throughout the year, the hot water is generated only as needed to maintain the prescribed temperature-humidity conditions in the main building. As part of the plant's original heating and air-conditioning system, the current heating-cooling equipment includes nine roof-mounted units. Each unit contains a blower and one coil. Plant air is recirculated through ducts across the coils to achieve the desired heating and/or air conditioning. When the plant needs to be heated, the hot water is delivered to overhead pipes and then circulated through each of the hot water coils. When the plant needs to be cooled, the hot water is routed to an absorption chiller which produces refrigerated water. Then the water, chilled to temperatures between 7° C (45° F) and 16° C (60° F), is circulated through each of the cold water coils.

Waste Loading System--

This system (see Figure 48) includes a hopper with a hinged door, a charging ram, a guillotine type of fire door, and a hydraulic power assembly with a control panel. Fabricated of hot rolled steel plate, the hopper is 1.8m (72 in.) long, 1.3m (51 in.) wide, and 0.8m (32 in.) deep for a capacity of 1.9m^3 (72 ft^3). Its door, also fabricated of hot rolled steel with formed steel structural members, is opened and closed hydraulically by a 6.4-cm

(2 1/2-in.)-diameter double-acting cylinder. The charging ram, a rectangular steel structure with a 1.2m × 0.6m (49- by 22-in.) face, is driven by two 8.9-cm (3 1/2-in.)-diameter double-acting cylinders operating in series. Fabricated of low carbon steel and lined with a 12.7-cm (5-in.)-thick A. P. Green Type KS4 castable refractory, the fire door is raised and lowered along a structural steel guide frame by a 6.4-cm (2 1/2-in.)-diameter double-acting cylinder. All hydraulic cylinders are powered by a 2.2-kilowatt (3-hp) motor and hydraulic pump system. An NEMA-4 enclosure includes the relays and switches for the automatic or manual control of the feeding cycle.

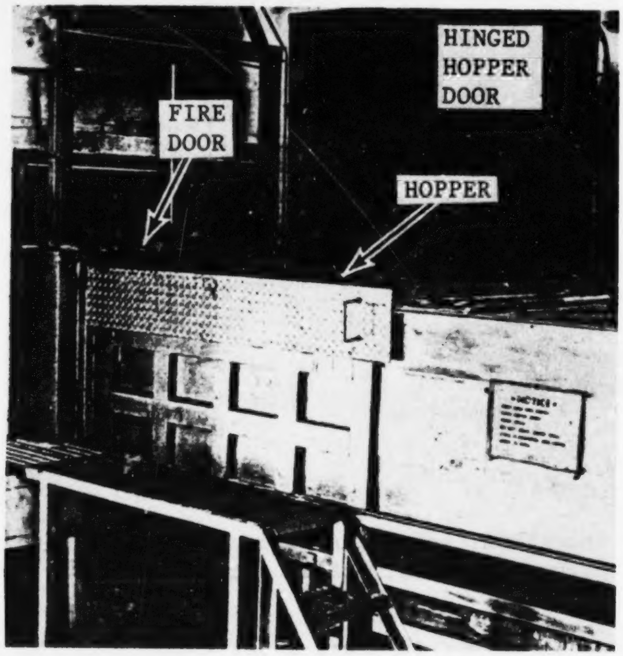


Figure 48. View of refuse loading system with fire door, hopper, and hinged hopper door indicated.

The transition section from the hopper to the primary combustion area passes through the facility wall. Constructed of 0.6-cm (1/4-in.) hot rolled steel and lined with a 12.7-cm (5-in.)-thick Kiser refractory, this section is 1.1m (42 in.) high, 1.6m (62 in.) wide, and approximately 0.5m (20 in.) long.

Primary Chamber--

The primary combustion chamber, called the pyrolysis chamber, is a horizontal cylindrical vessel constructed of 6.5-mm (1/4-in.)-thick hot rolled steel plate (see Figure 49). It has a 2.5m (100-in.) diameter and a 3.1m (123-in.) length. The vessel is supported by a 2.8m × 1.7m (112- × 68 1/2-in.) steel pad which is welded to the vessel and is mounted on a concrete pad outside the facility wall. The vessel shell is lined first with a 5.1-cm (2-in.)-thick fiber glass insulation and then with a 15.2-cm (6-in.)-thick A. P. Green Type KS4 refractory. Steel anchors welded to the shell about 45.7 cm (18 in.) apart secure the refractory to the shell. The lower one-third of the vessel interior, the hearth area, is lined with refractory brick.

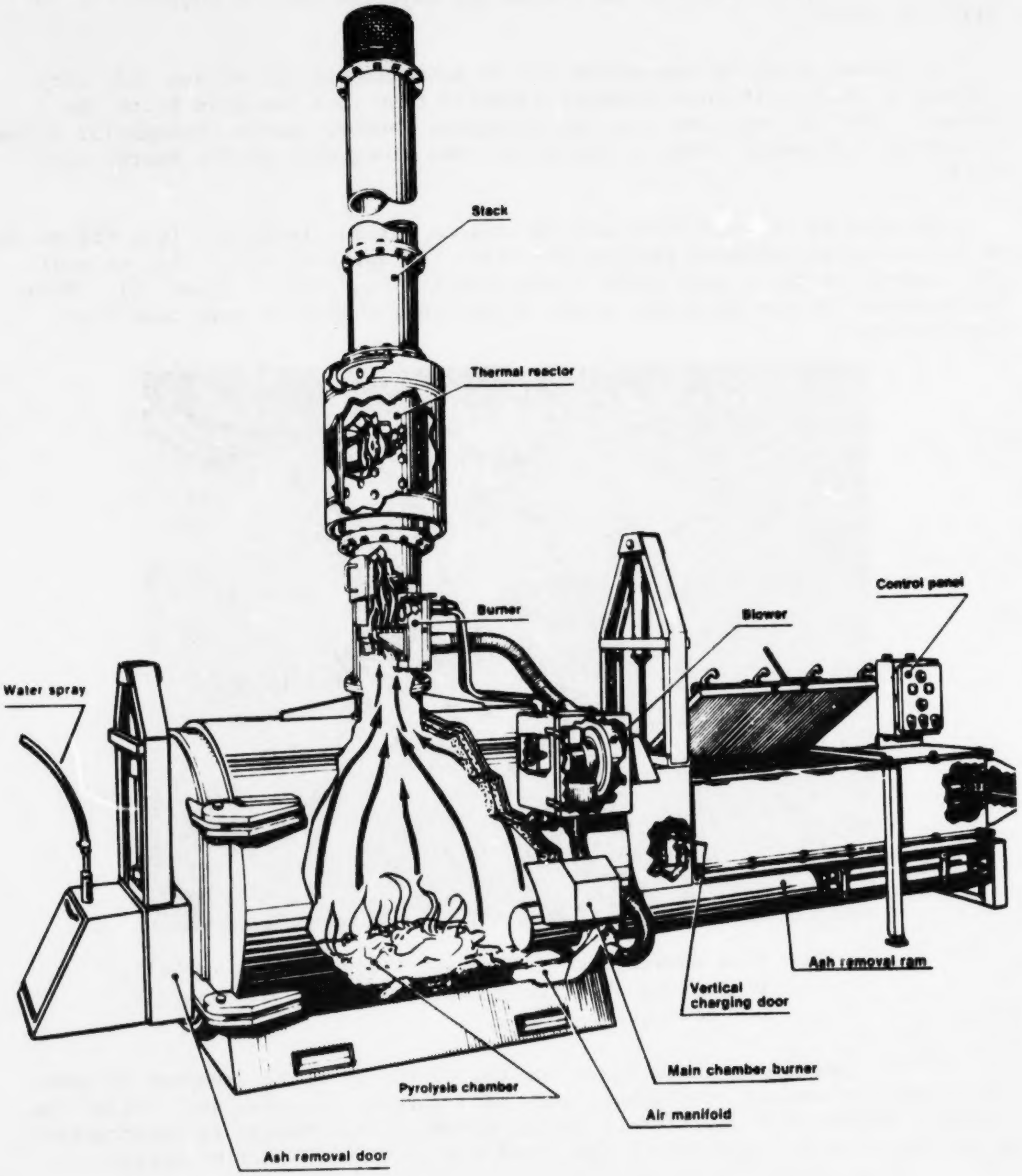

Stack
Thermal reactor
Burner
Blower
Control panel
Water spray
Ash removal ram
Vertical charging door
Main chamber burner
Pyrolysis chamber
Air manifold
Ash removal door

Figure 49. Three-dimensional, cutaway drawing of incinerator module in Marysville facility.

An Insicomite Model JS40 natural gas burner at the front of the pyrolysis chamber heats the chamber to 315° C (600° F) during start-up and automatically shuts off when the temperature exceeds 315° C (600° F). Although designed for 422 MJ/hr (400,000 Btu/hr), the burner was adjusted for 158 MJ/hr (150,000 Btu/hr).

A blower supplies combustion air at approximately 0.3m^3/sec (680 cfm) through a 15.2-cm (6-in.)-diameter flexible tube to a manifold below the burner. The air injected into the pyrolysis chamber passes through 132 5.5-mm (0.218-in.)-diameter holes in two tubes, one along each of the hearth side walls.

Nozzles at the one-third and two-thirds ceiling locations (see Figure 50) of the pyrolysis chamber provide the means for spraying water mist to cool the combustion gases when their temperatures exceed 649° C (1200° F). When the nozzles are not spraying, water drips continuously to keep them from overheating.

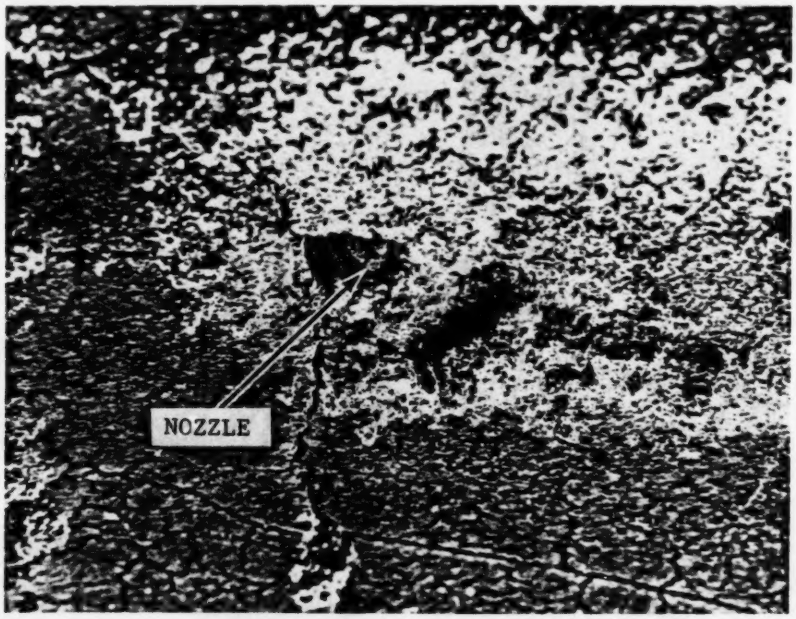


Figure 50. View showing one of the two spray nozzles installed in ceiling of primary chamber to cool excessively hot combustion gases.

As the combustion gases leave the top of the pyrolytic chamber to enter the secondary combustion chamber, they pass through an elbow duct called the throat. With a 43.2-cm (17-in.) inside diameter, the throat is constructed of 6.5-mm (1/4-in.) mild steel and lined with 7.6 cm (3 in.) of refractory.

The entire rear of the primary chamber swings completely open on a hinge. This unrestricted access permits bulk residue removal and refractory, air tube, and residue removal ram inspection and repair during shutdown.

Residue Removal System--

The residue accumulating on the hearth of the pyrolytic chamber is periodically pushed along the hearth length, through a vertically raised door, and into an ash hopper by a cylindrical ram. On the same carriage supporting the refuse-charging ram but below it, the residue removal ram (see Figure 49) has a 30.5-cm (12-in.) diameter and is also driven by a double-acting cylinder. Like the fire door, the residue door is a guillotine type operated by a double-acting cylinder. The residue door opening is 66.0-cm (26-in.) wide and 81.3-cm (32-in.) high. These hydraulic cylinders are powered by the same 2.2-kilowatt (3-hp) motor and hydraulic pump system that serves the hydraulic cylinders in the waste loading system.

At the removal end of the ash hopper is a manually opened door which is hinged at the top. A nozzle at the top of the hopper sprays water mist to cool the residue before it is manually shoveled into refuse containers. At the left of the side view of the combustion chambers in Figure 51 is the original automatic residue removal system which contained a magnet to recover ferrous materials in the residue. However, the system was removed when the smaller than anticipated metal amounts and residue quantities did not warrant its continued operation.

Secondary Chamber--

The secondary combustion chamber, called the thermal reactor, is an integral part of the horizontal cylindrical flue gas duct which extends from the elbow duct, through the wall of the building, and to the duct leading to the exhaust stack inside the building (see Figures 49 and 51). With a constant 53.3-cm (21-in.) inside diameter, the flue gas duct is constructed of mild steel and lined with a 7.6-cm (3-in.)-thick castable refractory rated up to 1649° C (3000° F). This duct has two flanged sections bolted together. The first, which extends 0.9m (3 ft) from the elbow duct, contains three burners; and the second, which extends from the end of the first section to the stack gas inlet duct, contains a 96.5-cm (38-in.)-long inspirator section with a concentric aspirator around its length.

The three burners are mounted in the same plane perpendicular to the duct longitudinal axis and are equidistant from each other. Like the burner for the pyrolytic chamber, each of the three burners is an Insicomite Model JS40 designed for 422 MJ/hr (400,000 Btu/hr) but adjusted for 158 MJ/hr (150,000 Btu/hr). Combustion air is supplied to the burners at approximately 0.3m^3/sec (680 cfm) by the same blower which supplies air to the pyrolytic chamber. These burners ignite the pyrolytic gases from the primary chamber and maintain the temperature at 649° C (1200° F). Above each of the three burners is a refractory-lined inspection port.

The inspirator section consists of a series of equally spaced 1.8-cm (21/32-in.)-diameter holes arranged in equidistant longitudinal lines around the duct circumference. The air entering at each end of the aspirator is drawn through the holes by natural aspiration. Additional air enters the flue gas stream through a 1.3-cm (1/2-in.)-wide slit in the duct downstream of the inspirator section. A moveable ring around the slit controls the amount of additional air introduced through the slit.

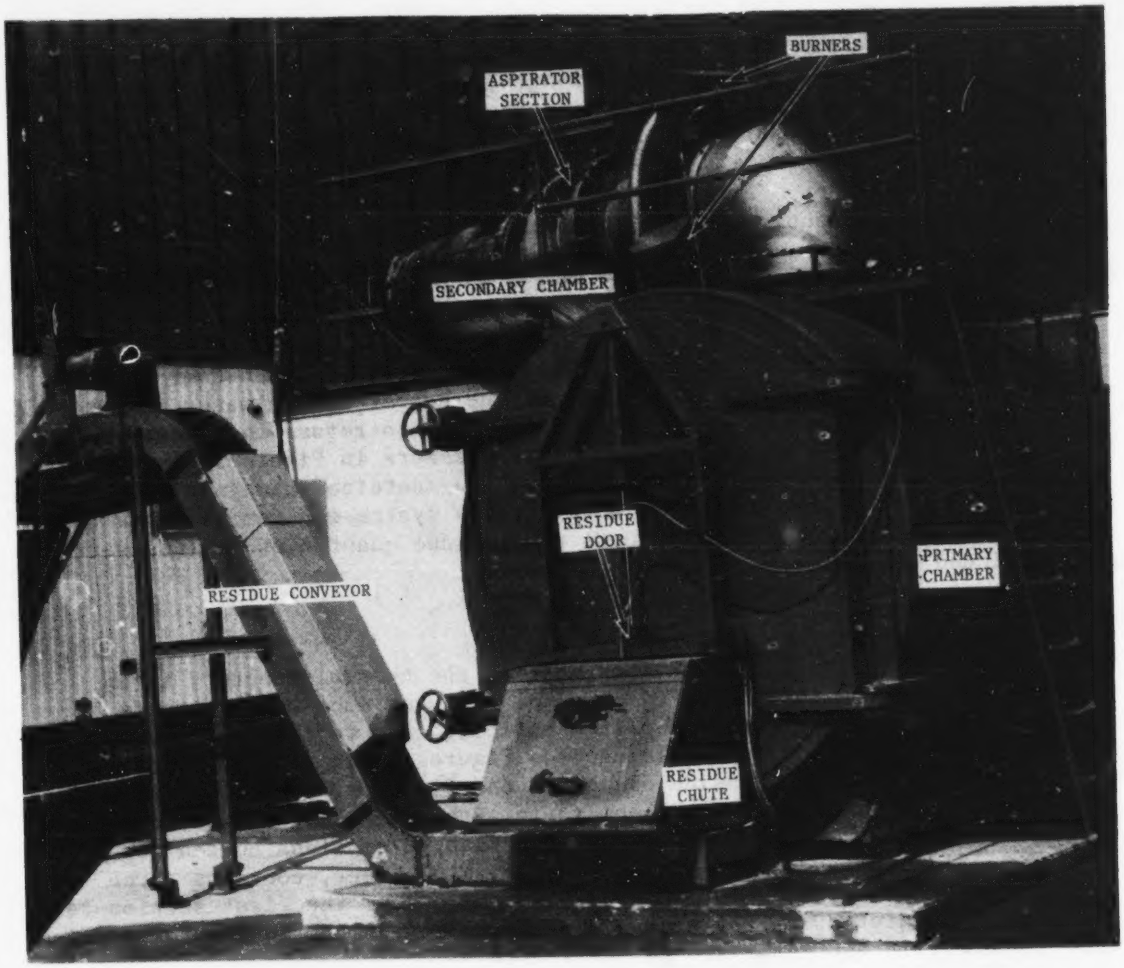

BURNERS
ASPIRATOR SECTION
SECONDARY CHAMBER
RESIDUE DOOR
PRIMARY CHAMBER
RESIDUE CONVEYOR
RESIDUE CHUTE

Figure 51. Side view of combustion chambers showing at left the original automatic residue removal system.

Exhaust Stack--

The gas exiting the flue gas duct flows into the exhaust stack where it is either discharged to the atmosphere or drawn into the heat recovery boiler. Based inside the building, the exhaust stack extends through the roof to a total height of 12m (40 ft). The stack has an inside diameter of 53 cm (24 in.) and is constructed of mild steel with a 7.6-cm (3-in.)-thick lining of A. P. Green refractory.

Heat Recovery System--

The heat recovery system consists primarily of a York-Shipley Series No. 565 firetube boiler (see Figure 52). Rated at 131 kilowatts (175 hp) the boiler is a 3-pass design and has fireside heating and waterside surfaces of 81.3m^2 (875 ft^2) and 89.1m^2 (959 ft^2), respectively. The boiler produces hot water at 104° C (220° F) and 30 psig.

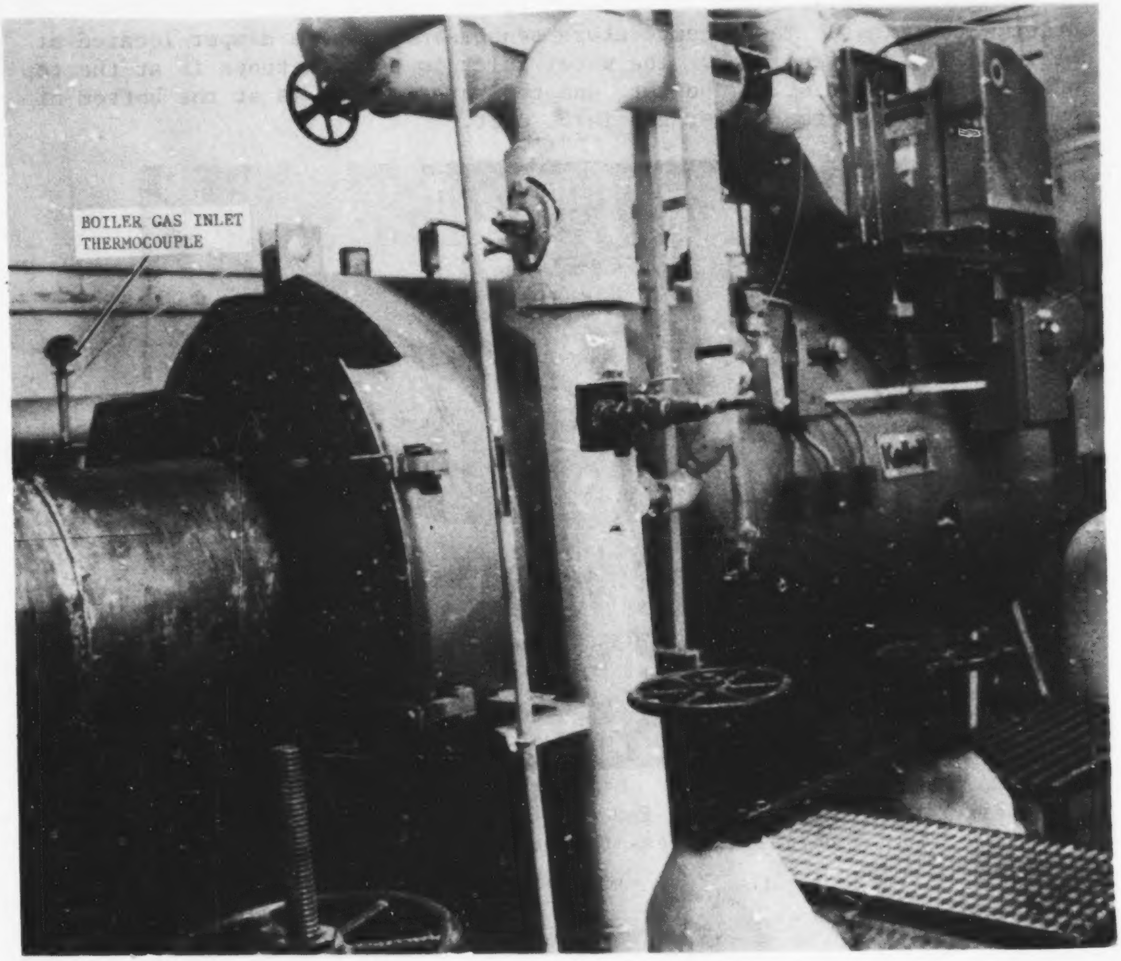


Figure 52. Side view of hot water boiler with thermocouple for boiler entrance duct indicated.

The Trane absorption chiller, rated at 219.5 Mg (242 tons) of cooling, requires $0.02m^3/sec$ (320 gpm) with a temperature difference of 121° C (250° F) in and 104° C (220° F) out.

When hot water is required, the combined action of a motor-modulated damper and an induced draft fan in the boiler gas outlet duct draws the flue gas down the stack from the level where it enters the stack to the boiler gas inlet duct. From there the gas flows to the boiler gas inlet at the near end, makes three passes through the boiler, then exits the boiler through the gas outlet at the boiler far end. After passing through the induced draft fan (see Figure 53), the gases flow through the boiler outlet gas duct to the stack at a level above the flue gas inlet to the stack for its discharge to the atmosphere. The flue gas flow rate is controlled by a thermocouple in the stack gas inlet duct and by temperature sensors in the boiler inlet and outlet water lines. These temperature sensors modulate a damper located at the induced draft fan inlet. The water inlet to the firetubes is at the top and near the center of the boiler, and the water outlet is at the bottom of the firetubes near the boiler gas inlet duct.

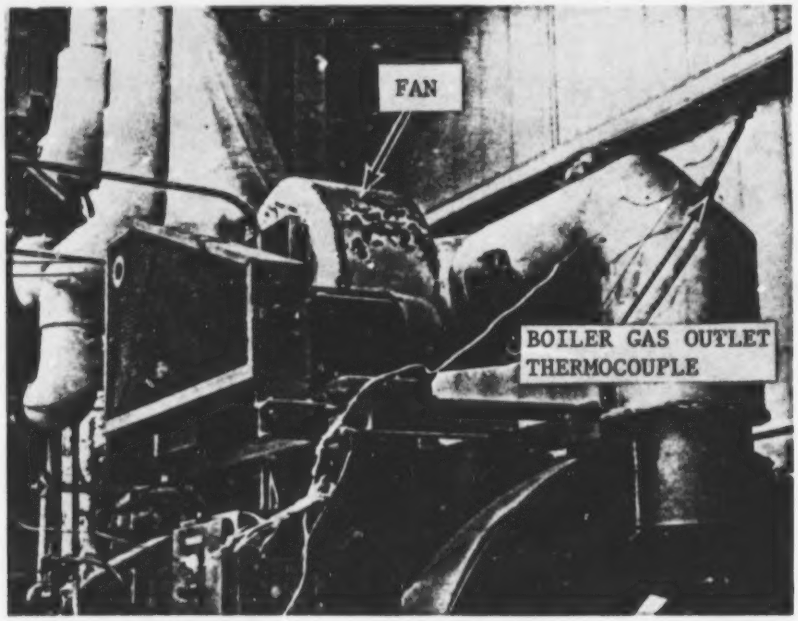


Figure 53. View showing induced draft fan and thermocouple for boiler exit gas temperature.

Operation

Figure 54 shows a flow diagram of the incineration-heat recovery processes.

Refuse Loading--

A fork-lift vehicle transports the packing and shipping scraps and other solid waste in small containers to the refuse hopper (see Figures 55 and 56). When the hopper door is opened after the previous loading cycle, the vehicle operator lifts the containers and dumps the refuse into the hopper. Then the operator depresses the START button on the control panel (see Figure 57) to activate the following automatic operations in the given sequence:

(1) The hopper door closes.

(2) If the temperature in the pyrolysis chamber is below 649° C (1200° F), the fire door opens.

(3) If the temperature at the exit of the inspirator chamber is above 982° C (1800° F), the fire door opening is delayed until the temperature falls below 982° C (1800° F).

(4) As the fire door opens, the charging ram pushes the refuse into the pyrolytic chamber and then partially withdraws 10.2 cm (4 in.) from the door until the fire door closes completely.

(5) If refuse blocks the complete door closing, the door rises and the ram moves forward again to clear the obstruction. If the door does not completely close after two more ram thrusts, an alarm sounds for the manual removal of the obstruction.

(6) When the fire door closes completely, the ram returns to its starting position and the hopper door opens.

The normal loading cycle takes about 100 seconds.

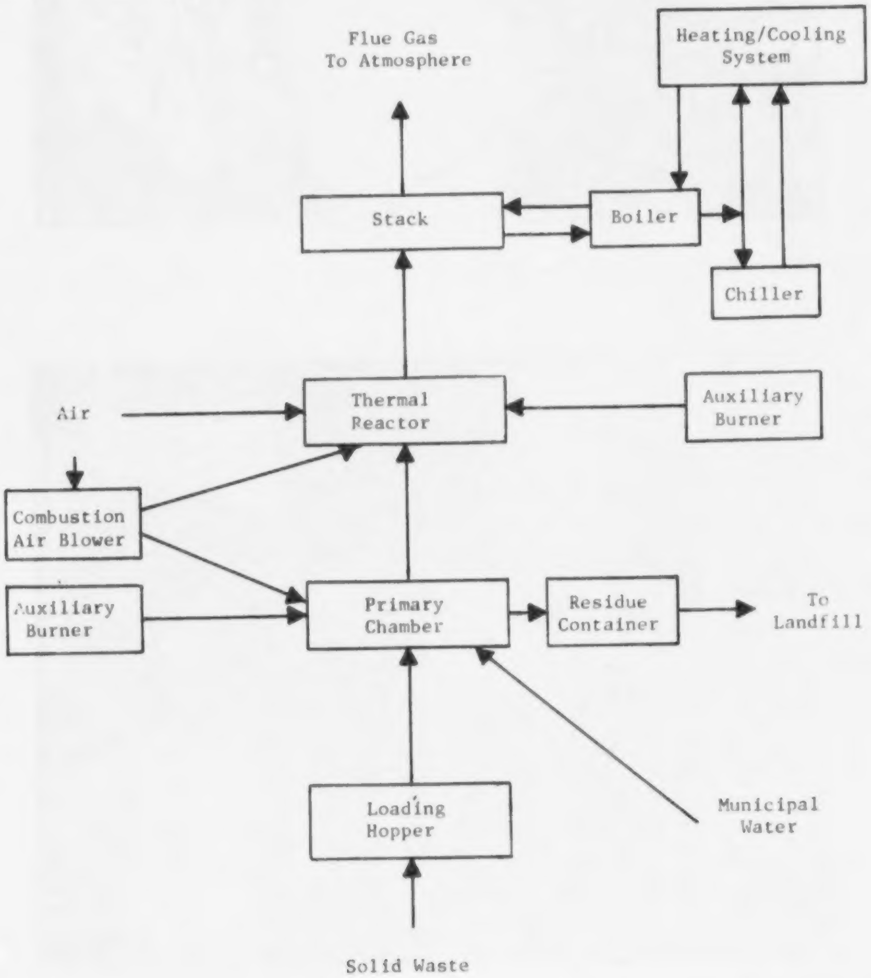

Flue Gas
To Atmosphere
Heating/Cooling System
Stack
Boiler
Chiller
Air
Thermal Reactor
Auxiliary Burner
Combustion Air Blower
Auxiliary Burner
Primary Chamber
Residue Container
To Landfill
Loading Hopper
Municipal Water
Solid Waste

Figure 54. Flow diagram of incineration-heat recovery processes in Marysville facility.

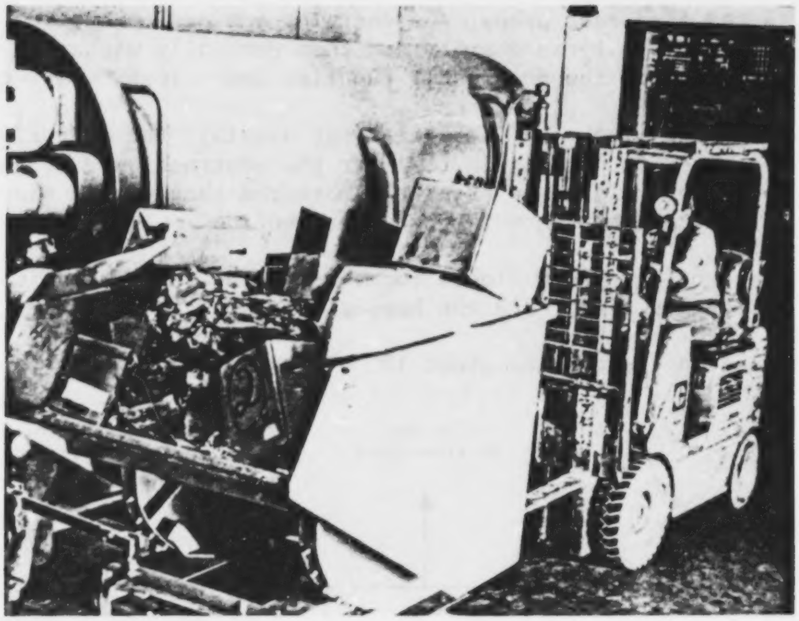


Figure 55. Fork-lift vehicle with refuse load beside refuse hopper.

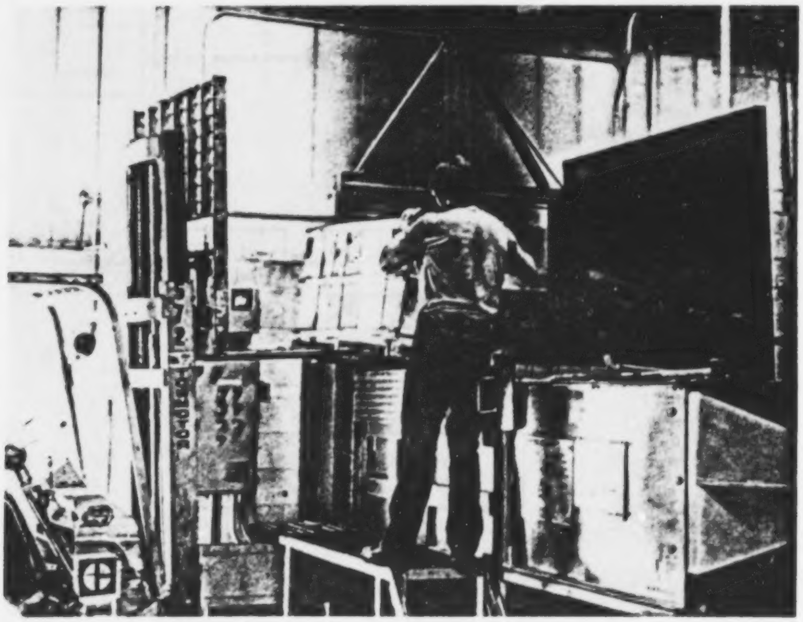


Figure 56. View showing manual removal of bulky objects on fork-lift vehicle for their placement in refuse hopper.

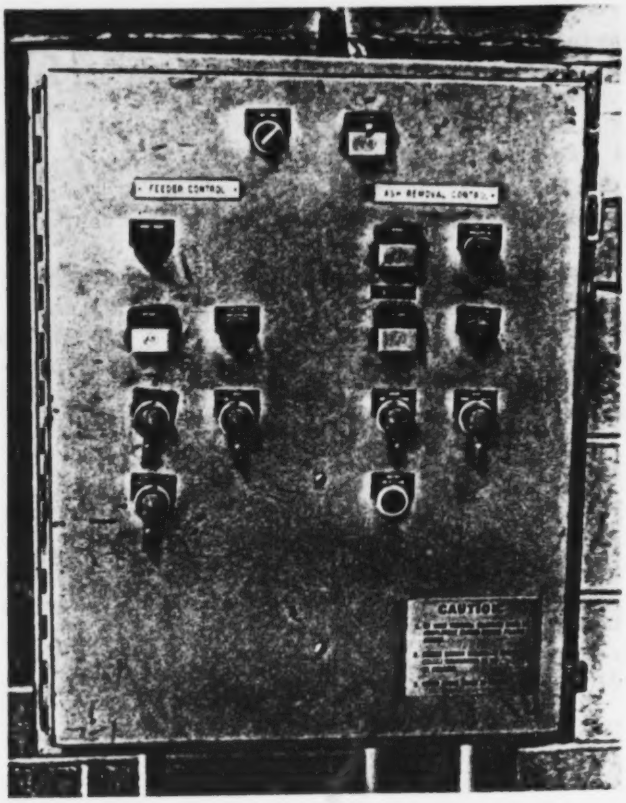


Figure 57. Control panel for automatic cycling of incinerator operations.

Chamber Operations--

During start-up, the burner in the pyrolysis chamber heats this chamber to 316° C (600° F). The refuse near the orifices of the two underfire air tubes along the hearth side walls combust rapidly at a very high temperature. As the combustion products are agitated upward through the waste, they promote additional gasification. When the temperature reaches 649° C (1200° F), all refuse volatiles become gasified. While carbon-rich char residuals settle on the hearth, the retention time is long enough to eventually reduce them to ash. If the temperature exceeds 649° C (1200° F), the nozzle at the top of the pyrolysis chamber sprays a water mist into the hot gas to lower the temperature. The manufacturer supplied performance data indicates that the pyrolysis chamber operates at 30 percent of the air required for stoichiometric combustion.

The combustion gases leave the pyrolysis chamber at about 649° C (1200° F). As the gases enter the burner section of the thermal reactor, they are ignited by the three burners in this section. Then as the gases pass through the inspirator section, the aspirated air intensifies the combustion and elevates the temperatures to between 982° C (1800° F) and 1093° C (2000° F). When the temperature reaches 982° C (1800° F), the three burners are turned off and not turned on again until the temperature of the combustion gas leaving the pyrolysis chamber drops below 649° C (1200° F). The thermal reactor operates at a maximum of 150 percent of stoichiometric air.

The amount of excess air supplied to the inspirator section is controlled by plugging the 1.8-cm (21/32-in.)-diameter holes. This control technique is principally suited to a waste stream which has a constant composition.

As the flue gases reach the 1.3-cm (1/2-in.)-wide split in the duct downstream of the inspirator section, they receive additional air to carry the combustion process to completion and to provide the amount of air mass needed for the gas flow drawn through the boiler by the induced draft fan. The amount of air introduced through the split is controlled by manually adjusting the coverage of the moveable ring over the split.

A single thermocouple in the pyrolysis chamber activates the following automatic operations: (1) the refiring of the burner in the pyrolysis chamber when the chamber temperature drops below 316° C (600° F), (2) the lockout of the refuse loading system when the chamber temperature is above 982° C (1800° F), (3) the turn-on of the water spray system in the pyrolysis chamber when the chamber temperature exceeds 649° C (1200° F), and (4) the refiring of the three burners in the thermal reactor when the temperature of the combustion gases leaving the pyrolysis chamber falls below 649° C (1200° F).

Residue Removal--

Periodically the ash and other residue accumulating on the hearth of the pyrolysis chamber are automatically removed by depressing the ASH RAM button on the control panel beside the refuse loading system. As the guillotine-type door leading to the ash hopper is raised, the ash ram (see Figure 58) pushes the residue along the hearth until its face is 20.3 cm (8 in.) away from the door entrance. Then the ram withdraws to its starting position and the door is closed to complete the cycle. The complete cycle requires about 60 seconds. The 20.3 cm (8 in.) of residue left in front of the ash door serves as a seal to prevent cold air from entering the pyrolysis chamber when the ash door is opened.

As the residue is discharged into the ash hopper, the nozzle at the top of the hopper sprays a water mist so that the residue can be sufficiently cooled for its manual shoveling into refuse containers.

In addition to ash removal, the ram is also used periodically to stir the ash bed for better combustion.

Hot Water Production--

The heat recovery system is integrated with the incinerator system by a Honeywell temperature control in the boiler control panel. Connected to a thermocouple in the stack gas inlet duct, the temperature control is set at 260° C (500° F). When the flue gas temperature exceeds 260° C (500° F), the temperature control allows the boiler controls to activate the damper-modulating motor to open the damper and turn on the induced draft fan to draw the flue gases through the boiler system. Conversely, when the flue gas temperature falls below 260° C (500° F), the temperature control activates the motor to close the damper and turns off the fan.

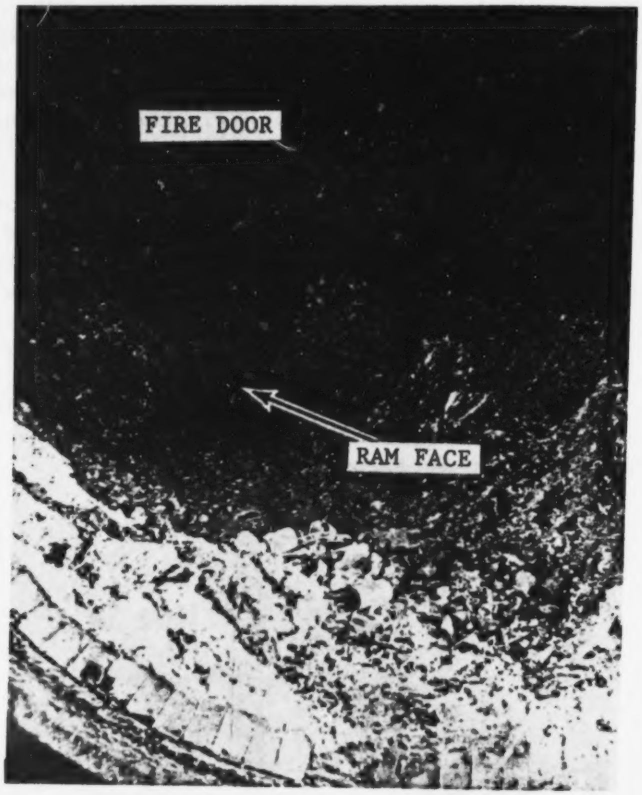


Figure 58. Rear view of primary chamber with fire door and ram face indicated.

While the flue gas temperature is over 260° C (500° F), the temperature sensors controlling the damper and fan operations are the operating and high temperature limit switches in the boiler inlet and outlet water. While the operating temperature limit switch and the high temperature limit switch for the inlet water are set at 71° C (160° F) and 82° C (180° F), respectively, those for the outlet water are set at 110° C (230° F) and 116° C (240° F). The switches for the boiler inlet water are the normal operating controllers. When the water temperature reaches either operating temperature limit, the damper partially closes to limit the flow of the flue gas through the boiler system. If the water temperature reaches either high temperature limit, the damper closes and the fan turns off. In addition to the temperature sensors, a boiler water level sensor also activates the damper closing and the fan shutdown when the water falls below the minimum level.

Site Preparation for Testing

The purpose of the testing was to provide detailed data on the facility performance. Various testing equipment was installed to provide the needed data. To facilitate collecting air emissions samples, a large scaffolding system was erected around the exhaust stack (see Figure 59). Test ports were installed in the stack to permit insertion of test probes into the stack. A tarpaulin over the scaffolding provided shelter for the test equipment and technicians. The SYSTECH mobile test laboratory, which housed continuous emission monitoring instrumentation, chemicals, other test equipment, and test records, was parked next to the building (see Figure 60).

To measure the energy input and output of the incinerator and boiler, a Btu meter (a flow meter and two temperature probes coupled to a readout, as shown in Figure 61) was installed. One thermocouple was installed in the boiler inlet water pipe. The other thermocouple and the flow meter were installed in the boiler outlet pipe. A multipoint strip chart recorder was connected to the existing thermocouples to monitor the flue gas temperature. The existing gas and water meter were monitored. Timers and counters were installed in the quench water, hydraulic, and induced draft fan electrical systems to measure power consumption and heat recovery time. The locations of the test probes are shown in Figure 62.

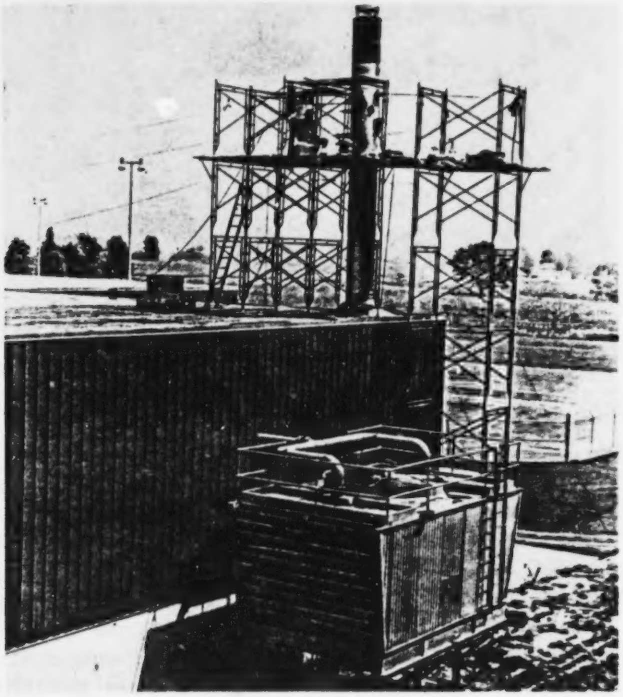


Figure 59. View of temporary scaffolding and platform for stack emission testing.

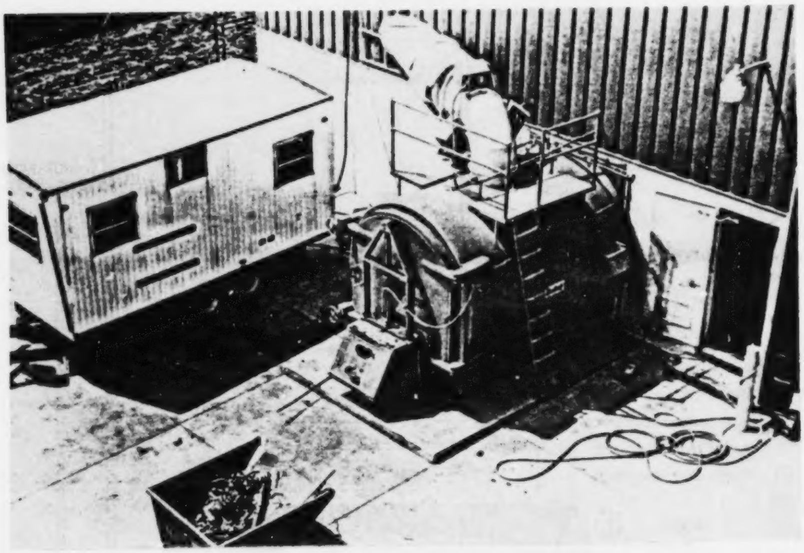


Figure 60. View of SYSTECH mobile trailer beside facility housing and combustion chambers.

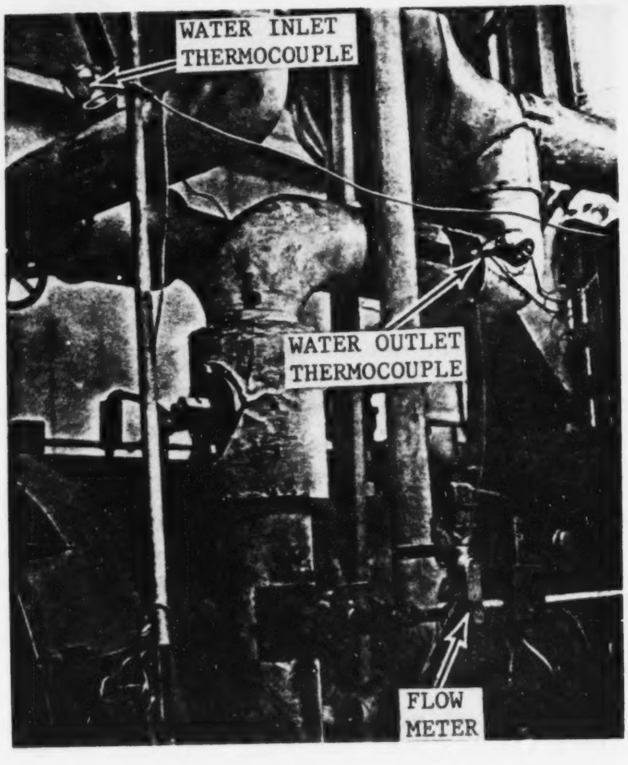

WATER INLET THERMOCOUPLE
WATER OUTLET THERMOCOUPLE
FLOW METER

Figure 61. View of boiler water lines with inlet and outlet thermocouples and Btu flow meter indicated.

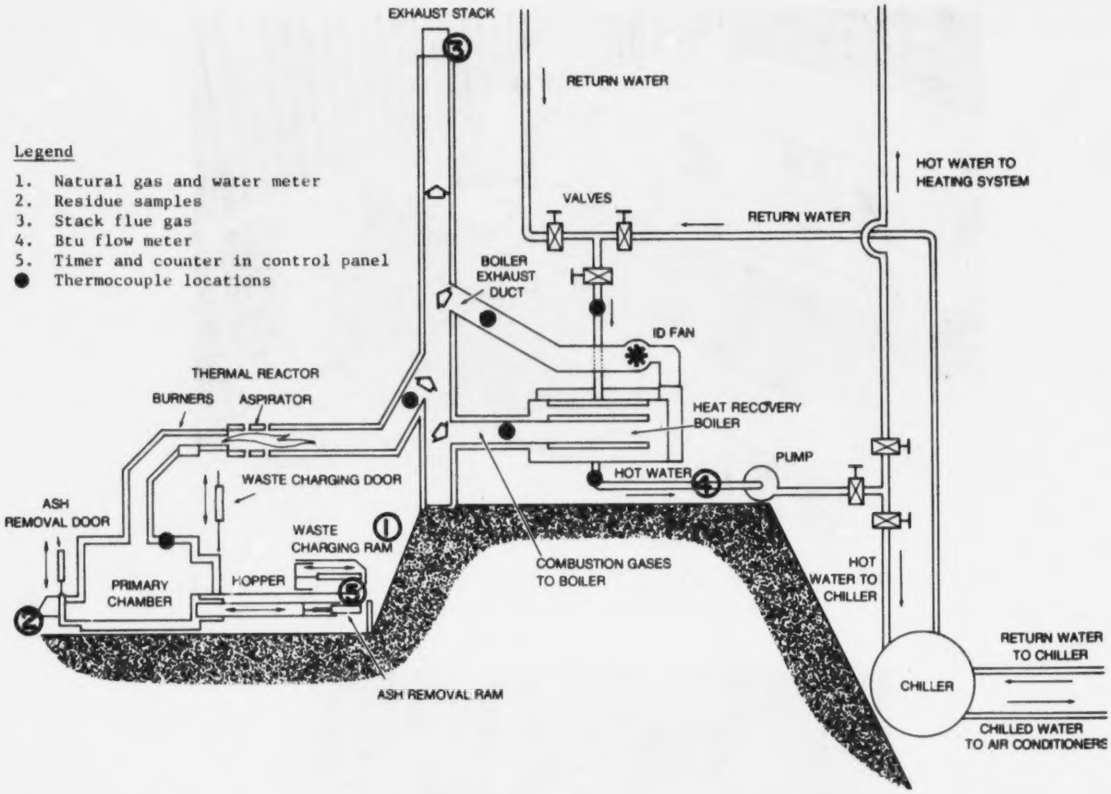

EXHAUST STACK
RETURN WATER
Legend
1. Natural gas and water meter
2. Residue samples
3. Stack flue gas
4. Btu flow meter
5. Timer and counter in control panel
● Thermocouple locations
HOT WATER TO HEATING SYSTEM
VALVES
RETURN WATER
BOILER EXHAUST DUCT
ID FAN
THERMAL REACTOR
BURNERS
ASPIRATOR
HEAT RECOVERY BOILER
PUMP
HOT WATER
WASTE CHARGING DOOR
ASH REMOVAL DOOR
WASTE CHARGING RAM
COMBUSTION GASES TO BOILER
HOT WATER TO CHILLER
PRIMARY CHAMBER
HOPPER
RETURN WATER TO CHILLER
CHILLER
CHILLED WATER TO AIR CONDITIONERS
ASH REMOVAL RAM
1
2
3
4
5

Figure 62. Locations of data collection points in Marysville facility.

Refuse Characterizing

Refuse Sampling and Analysis--

Throughout each of the three weekly field tests, each load of refuse delivered to the incinerator was weighed on a portable scale. Then the gross, tare, and net weights were recorded along with the refuse composition and the weighing and charging times.

At the outset of the first test, several loads were visually scanned to estimate their composition. Then these loads were hand-sorted and the components in each category were weighed to determine the accuracy of the visually estimated composition. Since the refuse was mostly wood and paper and the visually estimated composition differed by only 5 percent from that found by the hand-sorting and weighing method, the visual estimating method was used thereafter in the three tests.

Daily samples of the refuse were withdrawn for on-site moisture analysis. After the gross and tare weights were recorded, the samples were dried overnight at 105° C and the gross weights of the dried samples were recorded. The water percentage was computed by the following equation:

$$H_2O\% = \frac{\text{gross wt}_{\text{wet}} - \text{gross wt}_{\text{dry}}}{\text{tare wt}} \times 100$$

During the first field test, a composite refuse sample was sent to a commercial laboratory for an ultimate analysis. During the third field test, individual refuse samples were collected and sent to another commercial laboratory for the heat content and ultimate analysis of the wood and paper refuse components.

Refuse Characteristics--

Over the period of the three tests, the refuse burned totaled 51,768 kg (114,027 lb). Of this total, 34,024 kg (74,943 lb) or 65.7 percent was wood; 17,505 kg (38,557 lb) or 33.5 percent was paper; and the remaining 239 kg (527 lb) or about 0.5 percent was plastics, paint, inerts, textiles, and rubber. Table 44 summarizes the composition for each of the three test periods.

TABLE 44. MARYSVILLE WEEKLY REFUSE COMPOSITION FOR APRIL, JULY, AND AUGUST TESTS

Category	Test Period April kg	 (lb)	 July kg	 (lb)	 August kg	 (lb)	Total kg	 (lb)	Percent of Total
Total	13,151	(28,994)	25,652	(56,552)	12,919	(28,481)	51,722	(114,027)	
Wood	7,324	(16,147	18,684	(41,191)	7,985	(17,605)	33,993	(74,943)	65.7
Paper	5,768	(12,717)	6,940	(15,300)	4,782	(10,543)	17,490	(38,557)	33.8
Plastics			17	(38)	14	(31)	31	(69)	<.1
Paint	59	(130)					59	(130)	
Grease			12	(26)	20	(45)	32	(71)	<.1
Inert					82	(181)	83	(181)	.1
Textiles					13	(28)	13	(28)	<.1
Rubber					22	(48)	22	(48)	<.1

The moisture content of the wood ranged from 7 to 11 percent with the average being 9.3 percent. The moisture content of the paper ranged from 6 to 11 percent with the average being 7.6 percent. Table 45 summarizes the moisture content results for each of the three field tests.

TABLE 45. MARYSVILLE WEEKLY MOISTURE CONTENT FOR APRIL, JULY, AND AUGUST TESTS

	Test period							
	April				July			
Category	As-received wt kg(1b)	Percent of moisture by wt	Wet wt kg(1b)	Dry wt kg(1b)	As-received wt kg(1b)	Percent of moisture by wt	Wet wt kg(1b)	Dry wt kg(1b)
Wood	7,324(16,147)	7.4	542(1,195)	6,782(14,952)	18,684(41,191)	9.2	1,719(3,790)	16,965(37,401)
Paper	5,768(12,717)	7.5	433(954)	5,336(11,763)	6,940(15,300)	6.8	472(1,040)	6,468(14,260)
Total	13,092(28,864)		975(2,149)	12,118(26,715)	25,624(56,491)		2,191(4,830)	23,433(51,661)

	Test period			
	August			
Category	As-received wt kg(1b)	Percent of moisture by wt	Wet wt kg(1b)	Dry wt kg(1b)
Wood	7,985(17,605)	10.8	862(1,901)	7,123(15,704)
Paper	4,782(10,543)	9.0	430(949)	4,352(9,594)
Total	12,767(28,148)		1,292(2,850)	11,475(25,298)

During the second field test, the Btu content of the wood ranged from 17.7 to 18.39 MJ/kg (7612 to 7906 Btu/lb) with the average being 18.1 MJ/kg (7758 Btu/lb). The Btu content of the paper ranged from 17.1 to 18.9 MJ/kg (7370 to 8126 Btu/lb) with the average being 17.9 MJ/kg (7693 Btu/lb). Table 46 compares the wood and paper Btu results with the values published by Purdue University. While the Btu results for wood differed by 10 percent from the published values, the Btu results for paper differed by only 2 percent from the published values. The laboratory values were used for the detailed analysis.

Table 47 summarizes the ultimate analysis of the refuse.

TABLE 46. MARYSVILLE DAILY REFUSE CATEGORY HEATING VALUES FOR AUGUST TESTS

	Heating value MJ/kg(Btu/lb)					
Category	8/22	8/23	8/24	8/25	Average value	Published value
Paper	8.58(8126)	17.5(7525)	18.0(7751)	17.1(7370)	17.9(7693)	17.6(7572)
Wood	18.40(7906)	17.7(7612)	18.1(7760)	18.0(7753)	18.0(7758)	20.0(8613)

TABLE 47. MARYSVILLE REFUSE ELEMENT ULTIMATE ANALYSIS FOR JULY TESTS*

Element	Percent of total by weight	Element weight kg(lb)
Carbon	43.9	11,261(24,826)
Hydrogen	5.6	1,436(3,167)
Oxygen	38.2	9,799(21,603)
Nitrogen	0.26	67(147)
Sulfur	0.15	38(85)
Inert	5.2	1,334(2,941)
Water	6.7	1,719(3,789)
Total	100.0	25,652(56,552)

* Based on laboratory analysis of composite April test samples.

Residue Characterizing

Residue Sampling and Analysis--

Whenever the residue was removed from the incinerator during each of the three field tests, it was weighed, and the residue removal time and the gross and tare weights were recorded. Then with any large metal pieces extracted, several 1-gallon jars were filled and sent to SYSTECH for further analysis.

At the SYSTECH laboratory, samples were first taken from each of the gallon jars for bulk density analysis and returned to the jars. Next the residue in each jar was dried overnight at 105° C and then milled until the residue passed through a 5-mm mesh screen. One batch of the milled residue was used to conduct a total combustibles test for unburned volatiles and carbon. A small portion of a second batch was retained while the larger part was placed in a lysimeter to produce leachate. Then the second batch with its twofold content of intact residue and leachate was sent to a commercial laboratory for the chemical and physical analysis of both the residue and the leachate. Finally, a third batch was sent to another commercial laboratory for the proximate analysis of the residue to determine its ash, carbon, volatile, sulfur, and Btu content.

Residue Characteristics--

Table 48 summarizes the residue characteristics for each of the three field tests. The bulk density was found to be 428 kg/m^3 (726 lb/yd^3). The residue was very white and contained metal pieces such as bolts, nails, and pieces of cans and glass. In the proximate analysis (see Table 49) with two samples and in the SYSTECH analysis with another two samples, the volatiles and carbon were between 0 and 10 percent of the residue content. Because of the color and long burndown cycle time, the percentage of unburned combustibles in most of the ash was likely closer to 0 percent than to 10 percent. The refuse reduction by weight was 94.6 percent.

TABLE 48. MARYSVILLE WEEKLY RESIDUE CHARACTERISTICS FOR APRIL, JULY, AND AUGUST TESTS

Test period	Refuse burned kg(lb)	Residue removed kg(lb)	Refuse reduction by weight	Residue % of inerts by weight*	% of unburned combustibles by weight*
April	13,053(28,777)	786(1,732)	94.0	97.25	2.75
July	25,652(56,552)	924(2,038)	96.4		
August	14,762(32,516)	1,156(2,548)	92.2		
Total	53,454(117,845)	2,866(6,318)	94.6		

* Average of two test samples.

TABLE 49. MARYSVILLE RESIDUE PROXIMATE ANALYSIS FOR AUGUST TESTS*

Element	Percent of total by weight (dry basis) Sample #1	Sample #2
Moisture	0.09	2.85
Volatiles	1.12	6.25
Ash	98.79	80.56
Fixed carbon	0	10.34
Sulfur	0	0
Total	100.00	100.00

* Two samples taken on 8/22/79.

System Mass Balance

The system mass balance compares the mass flow entering and leaving the incinerator-heat recovery system. The system inputs were the refuse, the combustion fan air, the auxiliary gas, the quench water, and the aspirator section air. The system outputs were the residue and the boiler exhaust flue gas.

With the weekly test of July 17 to 21, 1978, the second field test, chosen for the mass balance calculation, Appendix B details the input and output calculations, and Figure 63 presents the results based upon a 1-ton refuse input. The mass balance in this figure covers two time periods: one for 75.35 hours while the system was in full heat recovery operation and the other for 44.62 hours while the system was in burndown cycles. Excluding the combustion fan and the inspirator air, the measured inputs over the 120-hour test totaled 42.6 Mg (47 tons). The air input could not be measured and had to be computed by the difference method.

Water Balance--

The water balance was calculated to confirm the validity of the moisture values used in the energy efficiency calculations. Except for the addition of the quench water to the inputs, the water input and output sources were the same as those at North Little Rock and were similarly measured.

With the input and output calculations detailed in Appendix B, Figure 64 presents the resultant mass balance for water. As shown in this figure, the inputs and outputs totaled 36.61 Mg (40.36 tons) and 35.86 Mg (39.53 tons), respectively.

Mass balance 120-hour test*

Source	Input: Mg per Mg refuse or Ton per ton refuse	Input: % of Total	Output: Mg per Mg refuse or Ton per ton refuse	Output: % of Total
Refuse	1.00	4.99		
Cooling spray water	0.65	3.24		
Natural gas	0.02	0.10		
Combustion air	18.39	91.67		
Flue gases			20.01	99.80
Residue, dry			.04	0.20
Total	20.06	100.00	20.05	100.00

* Total refuse input 25.6 Mg (28.3 tons).

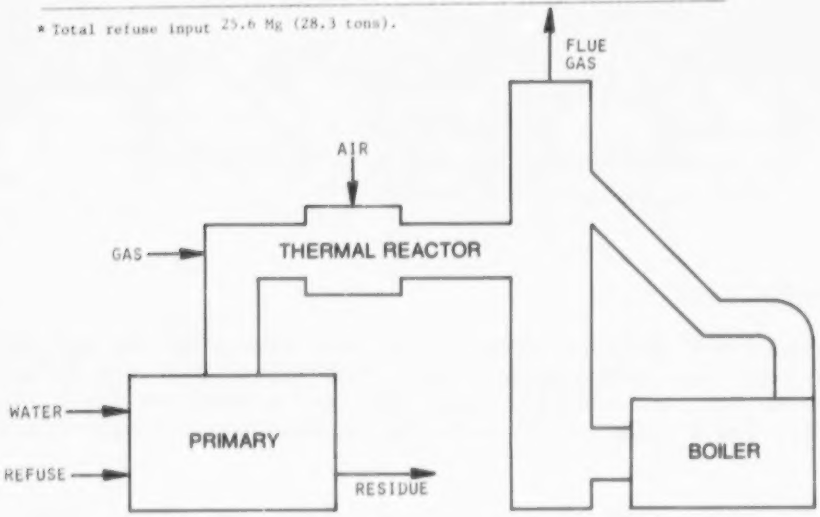
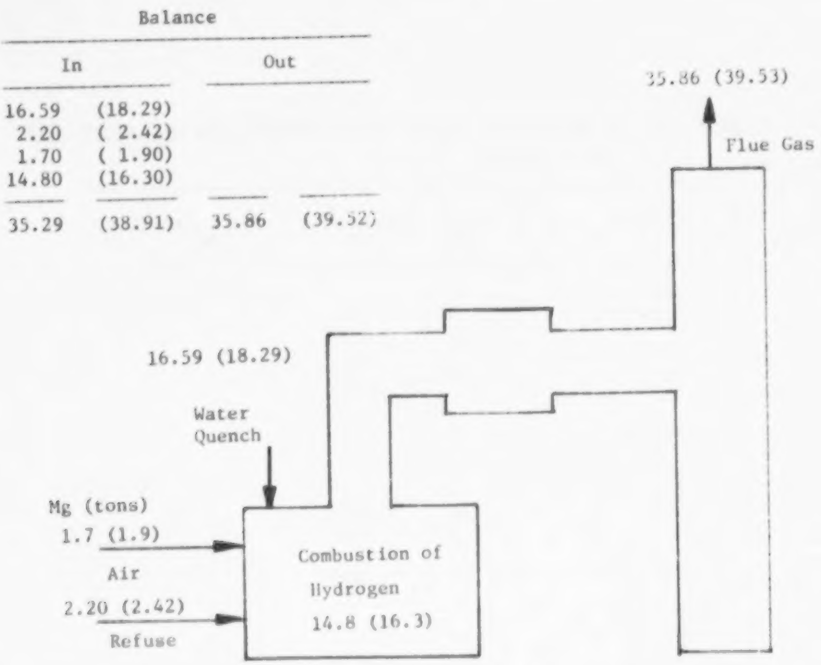


Figure 63. Mass balance for incineration-heat recovery processes in Marysville facility during the 120-hour (75.5-hour heat recovery) July field test.

Combustion Product Balance--

The combustion product balance was calculated to verify (1) the measurements used to compute the stack flow in the system mass balance, namely, the gas flow rate and the percentage of water by volume as measured by the Method 5 train and the percentages of oxygen, carbon monoxide, and carbon dioxide in the flue gas as measured by the tri-gas monitor and (2) the amounts of carbon, hydrogen, sulfur, nitrogen, and oxygen in the refuse as determined by the sort characteristic analysis and the ultimate analysis.

Since the elements found in the ultimate analysis combine with oxygen to form carbon dioxide, water vapor, nitrogen oxides, and sulfur oxides, the comparison of the combined weight of the elements with the measured weight of the stack flow is the expression for the combustion product balance.



Balance			
In		Out	
16.59	(18.29)		
2.20	(2.42)		
1.70	(1.90)		
14.80	(16.30)		
35.29	(38.91)	35.86	(39.52)

35.86 (39.53)
Flue Gas
16.59 (18.29)
Water
Quench
Mg (tons)
1.7 (1.9)
Air
2.20 (2.42)
Refuse
Combustion of
Hydrogen
14.8 (16.3)

Figure 64. Water balance for incineration-heat recovery processes in Marysville facility during the 120-hour (75.5-hour heat recovery) July field test.

The combustion product balance in Table 50 shows the amounts of the elements and their combustion products and of the stack mass flow as taken from the system mass balance.

The total calculated mass input was 511 Mg (563 tons) with 25 Mg (27 tons) of fuels, 469 Mg (517 tons) of air, and 17 Mg (19 tons) of quench water. The measured flue gas output was 514 Mg (567 tons).

Excess Air--

The excess air level can be expressed in percent as

$$\text{Excess air} = 100 \times \frac{O_2 - CO/2}{0.264N_2 - (O_2 - CO/2)}$$

The dry flue gas analysis for the second test was

$CO = 0$
$CO_2 = 9.4$
$O_2 = 10.5$
$N_2 = [100 - (CO + CO_2 + O_2)] = 80.1$

Substituting these values in the above expression yields an average excess air level of 98.6 percent.

TABLE 50. MARYSVILLE COMBUSTION PRODUCTS BALANCE FOR JULY TESTS

Source	Input		Output	
	Mg	(ton)	Mg	(ton)
Refuse				
Moisture	2	(2)		
C	11	(12)		
H_2	1	(1)		
O_2	10	(11)		
N_2	<1	(<1)		
Natural gas	<1	(<1)		
Combustion air				
Moisture	3	(3)		
O_2	109	(120)		
N_2	357	(394)		
Quench Water	17	(19)		
Flue gases*				
H_2O			36	(40)
CO_2			111	(122)
O_2			9	(10)
N_2			358	(395)
Total	511	(563)	514	(567)

*SO_x, NO_x, and CO were all less than 0.1 percent

Energy Balance

The energy balance compares the measured energy inputs and outputs. For this balance, the inputs were refuse, quench water, auxiliary fuel, and electricity. The outputs were the hot water generated, sensible heat and remaining energy in the residue, heat lost by radiation and convection, and sensible heat in the flue gases. While Appendix B details the input and output calculations, Figure 65 presents the resultant energy balance on an MBtu per ton of refuse input bases. Over the 120-hour test, the energy inputs and outputs totaled 436 and 409 MJ (413 and 388 MBtu), respectively. The difference of 27 GJ (25 MBtu) or 6 percent of the energy input was not accounted for.

The difference could be in the Btu water values, the radiation and convection losses, or the burndown cycle losses. Since the Btu meter cannot measure pockets of steam that could be generated in the boiler, it does not record all the energy. The radiation and convention losses and the burndown cycle losses were both calculated from average temperatures and conditions. Since these losses represent 38 percent of the total losses, errors from averaging and making assumptions could account for most of the energy difference.

Energy balance 120-hour test*

Source	Input: GJ per Mg of refuse	Input: (MBtu per Ton of refuse)	Input: % of total	Output: GJ per Mg of refuse	Output: (MBtu per Ton of refuse)	Output: % of total
Refuse	16.36	(14.07)	96.4			
Electricity	0.12	(0.10)	0.7			
Natural gas						
Heat recovery	0.29	(0.25)	1.7			
Burndown	0.21	(0.18)	1.2			
Residue				0.03	(.03)	0.2
Radiation and Convection						
Heat recovery				2.26	(1.94)	14.4
Burndown				0.82	(0.71)	5.3
Flue gases						
Heat recovery				4.19	(3.60)	26.7
Burndown				2.27	(1.95)	14.5
†Hot water (measured)				6.09	(5.24)	38.9
	16.98	(14.60)	100.0	15.66	(13.47)	100.0

*Total refuse input 25.6 Mg (28.3 ton)
†Hot water output by difference 7.41 GJ/Mg refuse (6.37 MBtu/ton)

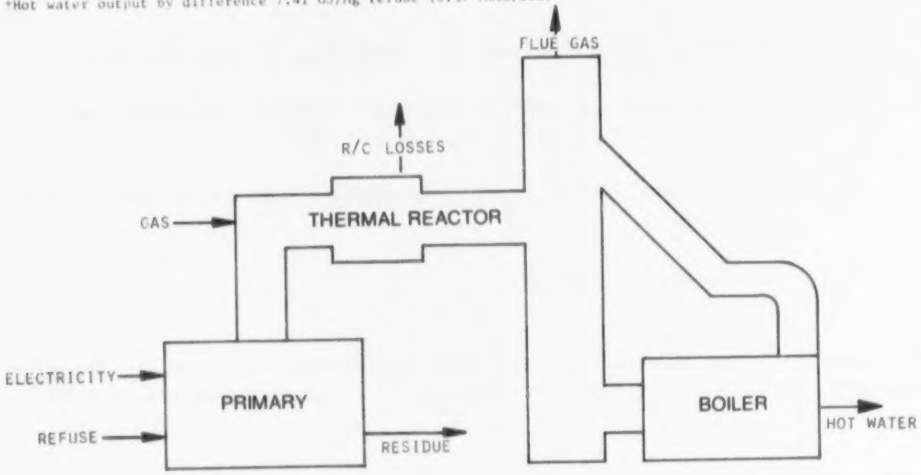


Figure 65. Energy balance for incineration-heat recovery processes in Marysville facility during the 120-hour (75.5-hour heat recovery) July field test.

Combustion Efficiency

Efficiency of Refuse Combustion--

The combustion efficiency of the refuse on a dry basis was calculated as follows by the heat loss method:

$$\eta = 1 - Q_r/Q_t$$

where Q_r = sensible heat and remaining energy in the residue

Q_t = total refuse energy

Substituting the values for Q_r and Q_t, as given in the energy balance in Figure 65, in the above equation yields an efficiency of 98 percent.

Efficiency of Incinerator System--

The efficiency of the incinerator system was that percentage of the total energy in the refuse and combustion air which after its conversion to hot gases was available to the heat recovery system. Using the heat loss method, the efficiency was computed by:

$$\eta = 1 - \frac{Q_r + Q_w + Q_{rc}}{Q_t}$$

and the net efficiency was computed by:

$$\text{net } \eta = 1 - \frac{Q_r + Q_{rc}}{Q_t - Q_w}$$

where Q_r = sensible heat and energy remaining in the residue

Q_w = latent heat of vaporization of refuse moisture and losses due to hydrogen combination

Q_{rc} = heat lost by radiation and convection up to the boiler operation

Q_t = total input energy

The substitution of the values from the energy balance in the above equations gives an incinerator efficiency of 75 percent and a net efficiency of 83 percent.

Energy Recovered

Hot Water Generated--

The volume and temperature of the hot water generated depends on the heating and cooling demands of the plant. To measure the heat generated in the hot water production of each weekly field test, a Btu meter was used. In addition, a timer was connected to the induced draft fan on the boiler to determine the time that flue gases were being drawn through the boiler. During the second field test, the induced draft fan was on during 95 percent of the two-shift operating time. The Btu meter indicated that 149,810 MJ (142 MBtu) were delivered to the heating and cooling system.

Because of the steam pockets that would not be measured by a Btu meter, the ASME Power Test Codes for hot water boilers require that the heat transferred in hot water production be calculated by the heat loss method.

The heat generated is the difference between the calculated total heat input and the calculated heat losses. Therefore, the usable energy delivered for the July test would be 182,515 MJ (173 MBtu) as taken from the energy balance.

As mentioned earlier in the discussion of the energy balance, not all this difference should be assigned to the usable energy output because of the possible calculation error in the radiation and convection losses and the burndown cycle losses. Consequently, the usable energy delivered lies between the measured 149,810 MJ (142 MBtu) and the calculated 182,515 MJ (173 MBtu).

System Energy Efficiency--

The system energy efficiency was calculated by the following equation for the heat loss method:

$$\eta = 1 - \frac{\text{heat losses}}{\text{total heat input}}$$

The total heat losses for the 120-hour energy balance shown in Figure 65 were 252,145 MJ (239 MBtu) and the total heat input was 435,715 MJ (413 MBtu). Consequently, the system energy efficiency was 42 percent for the week.

For the period that the system was being used for hot water recovery (75 hours), the energy inputs were gas, 7385 MJ (7 MBTU); electricity, 3165 MJ (3 MBtu); and refuse, 361,865 MJ (343 MBtu); and the losses were flue gases, 107,610 MJ (102 MBtu); radiation and convection losses, 58,025 MJ (55 MBTU); and residue, 1055 MJ (1 MBtu). Substituting these values in the heat loss equation yields a thermal efficiency of 53 percent.

The net thermal efficiency was 52 percent for the total time period and 64 percent for the heat recovery time period. The net thermal efficiency was 10 to 11 percent more than the thermal efficiency based on the as-received refuse.

Effectiveness of Boiler--

The boiler effectiveness was computed by the following equation:

$$E = \frac{T_{h_1} - T_{h_2}}{T_{h_1} - T_{h_2}}$$

where T_{h_1} = temperature of flue gas entering the boiler

T_{h_2} = temperature of flue gas exiting the boiler

T_{c_1} = temperature of feedwater entering the boiler

During the second test period, the T_{h_1}, T_{h_2}, and T_{c_1} temperatures averaged 1400°, 275°, and 160° F, respectively. Consequently, the boiler effectiveness was 90 percent.

Thermal Efficiency of Boiler--

While the effectiveness is the maximum theoretical performance of the boiler, the actual operational efficiency may be calculated by:

$$\eta = \frac{\text{heat transferred to water}}{\text{specific heat of gases into boiler}}$$

$$\eta = \frac{M_w (h_2 - h_1)}{M_g C_p (T_1 - T_2)}$$

where M_w = mass of water entering

h_2 = enthalpy of water leaving

h_1 = enthalpy of water entering

M_g = mass of flue gas entering

C_p = specific heat of flue gas entering

T_1 = temperature of flue gas entering

T_2 = temperature of flue gas leaving

The efficiency of the boiler with the higher heating value of the flue gas was 80 percent and that with the lower heating value of the flue gas was 84 percent.

System Effectiveness

Refuse Handling Capability--

The incinerator was capable of handling a wide variety of wood, paper, garbage, and other refuse produced in the assembly plant. While most of the refuse loads delivered by the fork-lift truck were dumped directly into the loading hopper, some with visible metal, such as banding straps, were manually sorted for the metal removal. In addition, bulky loose waste and the refuse in cans were hand-loaded to prevent spillage and load jamming.

Design and Actual Capacities--

The incinerator has a design capacity of 545 kg/hr (1200 lb/hr) of refuse input or 9.5 GJ/hr (9 MBtu/hr) energy input. The actual loading rates over the three test periods averaged 272.4 kg/hr (600 lb/hr), 50 percent of the design capacity, and the minimum and maximum feed rates were 180 and 635 kg/hr (400 and 1400 lb/hr). Table 51 shows the loading rates during each of the three field tests.

TABLE 51. MARYSVILLE DAILY REFUSE FEED RATES FOR APRIL, JULY AND AUGUST TESTS

Date	Time period	Δ Time hr:min	Weight fed Mg(lb)	Feed rate Mg/hr(lb/hr)
4/24	7:20 - 22:45	15:25	3.37(7,421)	0.22(481)
4/25	7:42 - 22:00	14:18	2.69(5,921)	0.19(414)
4/26	7:20 - 16:42	9:22	1.64(3,608)	0.17(385)
4/27	8:10 - 21:45	13:35	3.29(7,246)	0.24(533)
4/28	7:32 - 17:50	10:18	2.18(4,807)	0.21(467)
7/17	7:14 - 22:20	15:06	4.66(10,262)	0.31(680)
7/18	7:20 - 22:27	15:07	4.89(10,775)	0.31(713)
7/19	7:20 - 22:25	15:05	5.74(12,653)	0.38(839)
7/20	7:10 - 22:15	15:05	5.61(12,345)	0.37(818)
7/21	7:10 - 10:10	15:00	4.77(10,516)	0.32(701)
8/21	7:43 - 23:31	15:48	3.87(8,518)	0.24(539)
8/22	5:20 - 17:31	12:11	1.87(4,120)	0.15(338)
8/23	7:15 - 20:50	13:35	2.63(5,796)	0.19(427)
8/24	7:15 - 20:32	13:17	2.53(5,565)	0.19(419)
8/25	7:24 - 15:13	8:49	2.04(4,482)	0.23(508)
Total		187:01	51.77(114,036)	-- (---)
Average		12:28	3.45(7,602)	0.28(610)

Operation--

The incinerator is designed to function with minimum supervision and periodic preventive maintenance. At the Marysville facility, one man can readily operate the incinerator at the designed capacity during each shift. Most of the time only 50 percent of his time is required to operate the unit.

The delivery of waste varied widely in amounts and times. The unit was underfed most of the time, but occasionally it was so overfed (one large load fed to a cool incinerator) that flames passed through the boiler and out the stack. This is evidenced by Figure 66 which shows an overload period when the boiler entrance temperature was higher than the secondary chamber temperature. Figure 67 shows gas emission peaks caused by overfeeding.

Although the automatic residue removal ram in the primary chamber left most of the residue along the hearth sides, the remaining residue was easily removed manually through the rear access door. Since the incinerator was operated at only half of its capacity, it used more auxiliary fuel to maintain temperature in the secondary chamber.

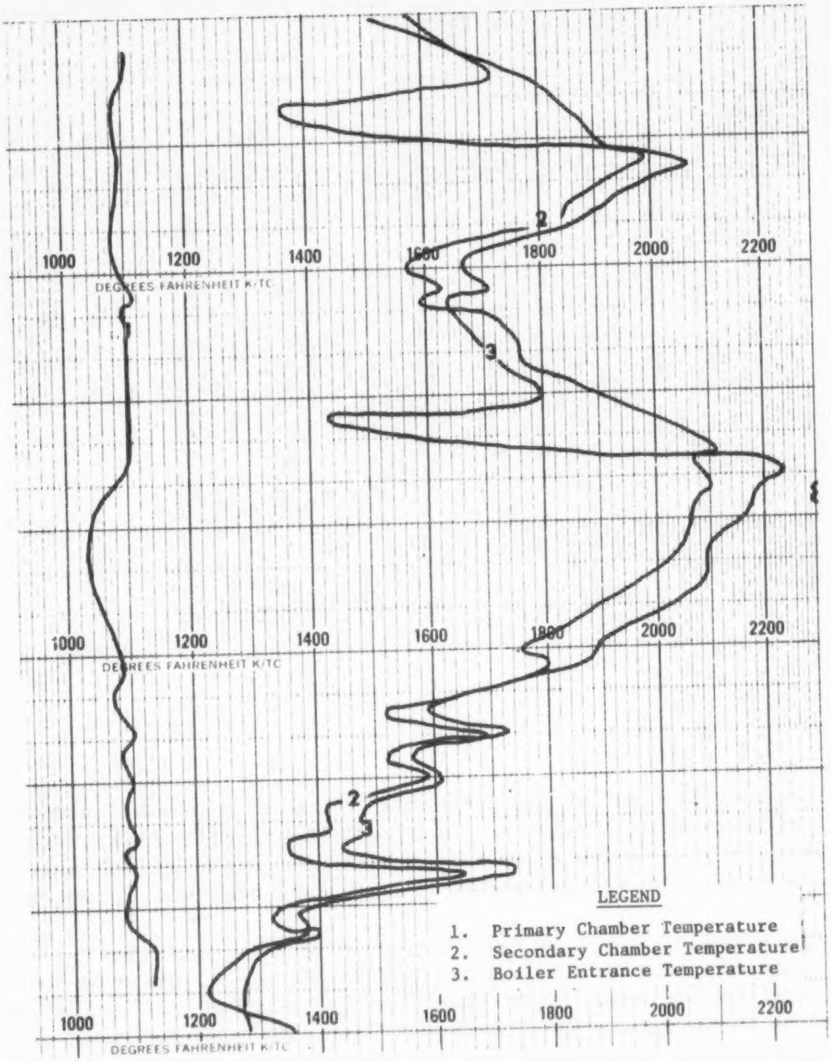


Figure 66. System temperatures during peak loading periods in Marysville facility.

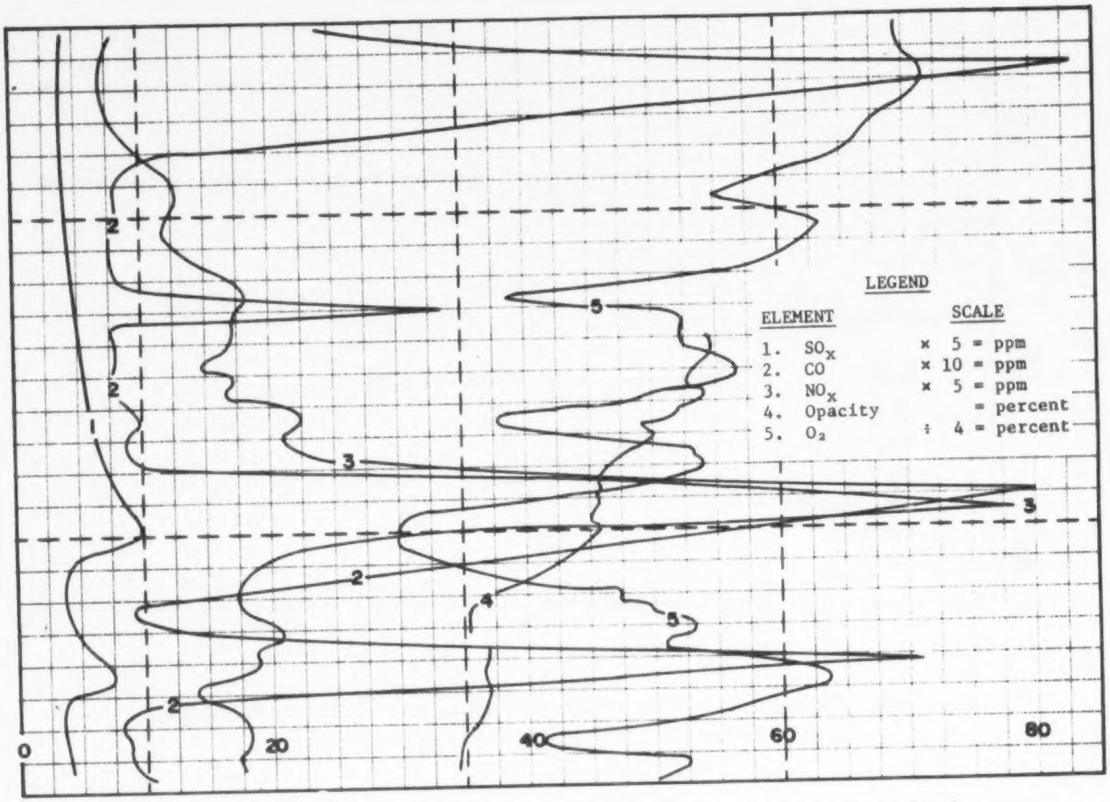


Figure 67. Stack emissions during peak loading periods in Marysville facility.

The daily burndown periods normally began about 10:30 p.m. During the last 1 to 2 hours before burndown, the incinerator was operated at near capacity rates. Since the boiler was inoperative during the burndown, much of the refuse energy was lost. During the July test it took about 8 hours in the burndown cycle for the temperature in the secondary chamber to fall from 760° to 204° C (1400° to 400° F) while the temperature of the primary chamber usually retained its normal operating level of 537.8° C (1000° F). During the April test, the operating temperature of the primary chamber was generally above 537.8° C (1000° F). Therefore, during the April test, more carbon was burned by the start of the burndown cycle. Consequently, during the burndown, the temperature of the primary chamber fell and the temperature of the secondary chamber dropped more rapidly than it had in the July test (see Figure 68). Similarly during the burndown, the carbon dioxide emissions in the April test dropped more rapidly than they had in the July test (see Figure 69).

Maintenance--

Except for scheduled preventive maintenance, such as oil-level checking, the only maintenance required during the three field tests was the cleaning of the induced draft fan blades. Weekly cleaning was necessary because the fan became unbalanced as particulates accumulated on the blades.

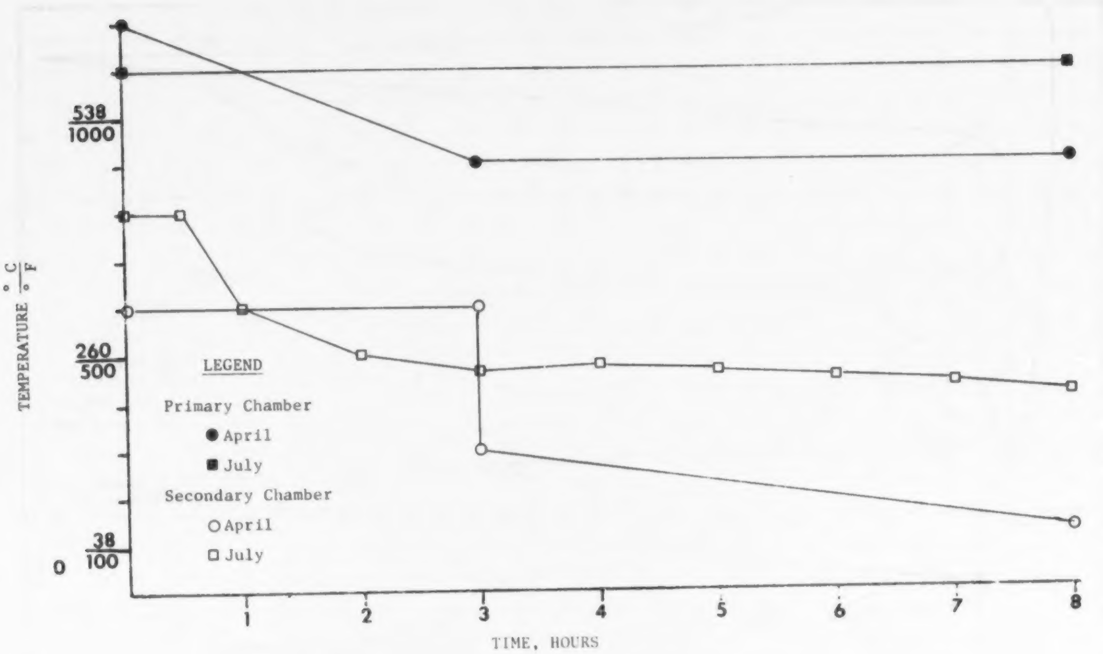


Figure 68. Temperature of combustion chamber during burndown periods in Marysville facility.

When the boiler was opened for tube cleaning and inspection in the second field test of July 1978, boiler tube test slips were inserted. When the boiler was reopened for the same purposes in January 1979, the test slips were removed. They exhibited a significant amount of particulate and slag buildup.

The refractory in the primary chamber required minor patching on the fire door, the throat area, and the ash removal door and area. The refractory around the water sprays (see Figure 50) was damaged by the constant water drip required for protection of the spray nozzle. The fire-brick floor proved sufficiently resistant to the abrasion of the ash ram and the residue removal tools.

Environmental Analysis

Stack Emissions--

During the three monitoring periods while the heat recovery system was operative, the flue gases exiting the exhaust stack were sampled periodically by (1) the filter in the modified EPA Method 5 train to capture particulates for mass flow rate and chemical composition analyses; (2) the impingers in the EPA Method 5, 7, or 8 trains to capture vapors and gases for mass flow rate and chemical composition analyses; and (3) the seven-stage inertial cascade impactor to capture particulates for size distribution analysis. When the heat recovery system was inoperative, the flue gases were too hot to allow sampling with the impactor and the EPA trains.

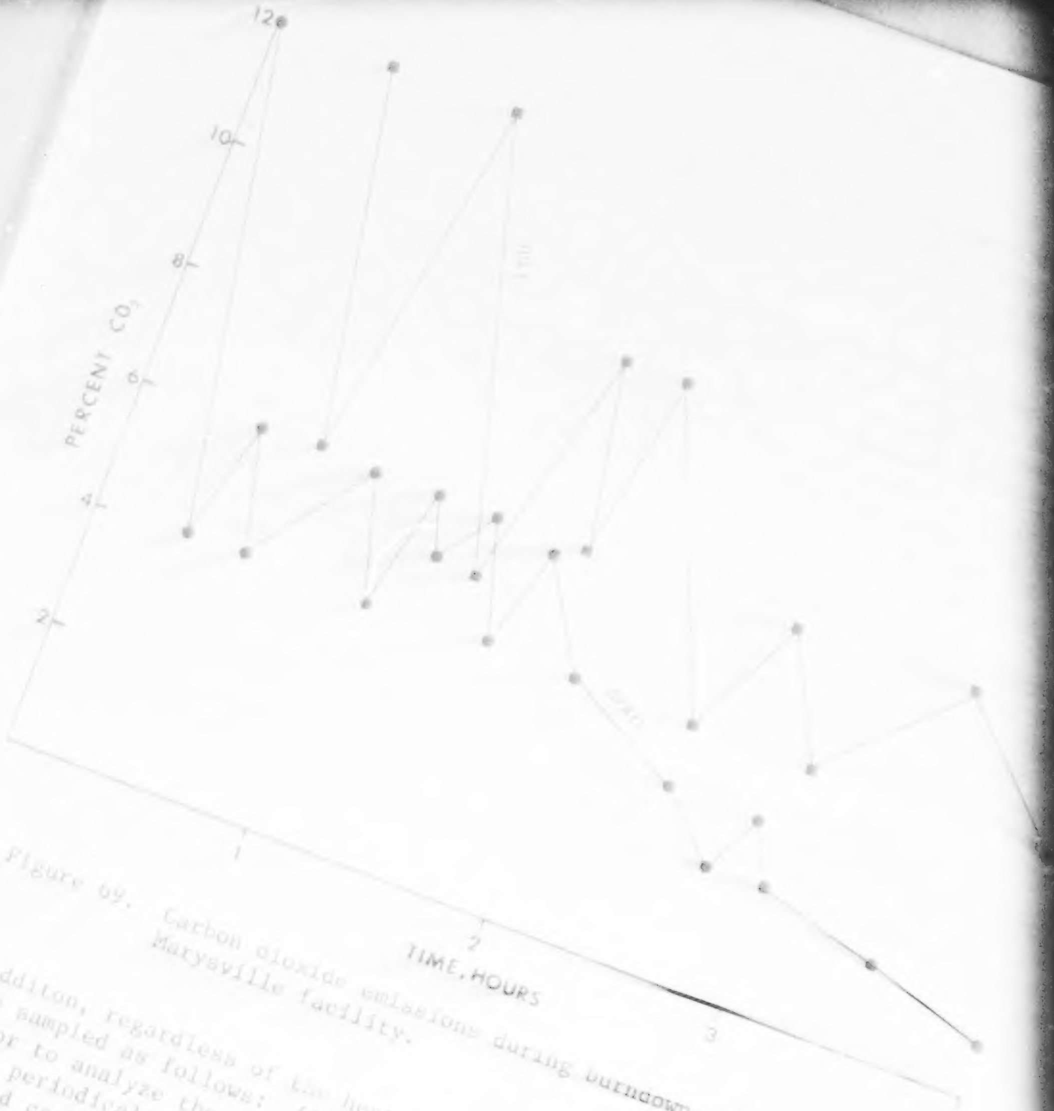


Figure 69. Carbon dioxide emissions during burndown periods in Marysville facility.

In additon, regardless of the heat recovery system operation, the flue gases were sampled as follows: (1) continuously by the TSI Electro-Chemical Cell Monitor to analyze the concentrations of oxygen and nitrogen and sulfur oxides; (2) periodically by an Orsat analyzer to analyze for oxygen, carbon monoxide, and carbon dioxide; (3) periodically by the gas chromatograph to capture hydrocarbons for chemical composition and concentration analyses of the hydrocarbons in the C_1 to C_6 ranges; and (4) continuously by two Beckman nondispersive infrared analyzers to determine the levels of carbon dioxide and carbon monoxide.

While the EPA trains and the seven-stage impactor were inserted inside and near the top of the exhaust stack to acquire flue gas samples, the other monitoring devices obtained samples by drawing flue gases from a port near the top of the stack, to a condensate trap, through a heated hose, and then to the SYSTECH mobile laboratory.

The emissions sampling results for the July field tests are presented in Table 52 and the other field tests are summarized in Table 53. Appendix A gives the results for the individual tests. The emission factors for July in pounds per ton of refuse charged are given in Table 54.

The flue gas flow rate averaged 4075 ACFM and 163.3° C (326° F) for all tests. On the average, the moisture in the flue gas was 12.1 percent of the total gas volume. Corrected to 12 percent CO_2, the particulate concentrations averaged 0.1586 g/m^3 (0.0693 gr/DSCF) over 16 tests with the maximum and minimum being 0.3401 g/m^3 (0.1547 gr/DSCF) and 0.0757 g/m^3 (0.0331 gr/DSCF). The size distribution analyses (see Figure 70) revealed that about 85 percent by weight of the particulates were smaller than 7 μm, and 50 percent by weight of the particulates were smaller than 0.5 μm.

Although the opacimeter functioned during the heat recovery periods, stack flames with the frequent heat recovery shutdowns damaged several probes. Since the opacimeter had to be recalibrated after each damaged probe was replaced, data could not be acquired for the successive heat recovery cycles. Some short-period results indicated that the opacity ranged from 15 percent at low loading to 45 percent at peak loading.

For the three test periods, the SO_x concentrations averaged 72.1 mg/m^3 (27.1 ppm) and had a maximum of 137.3 mg/m^3 (51.6 ppm), a minimum of 42.0 mg/m^3 (1.2 ppm), and a standard deviation of 24.6 mg/m^3. The NO_x concentrations averaged 176.3 mg/m^3 (92.3 ppm) and had a maximum of 223.9 mg/m^3 (117.2 ppm), a minimum of 94.9 mg/m^3, and a standard deviation of 37.7 mg/m^3.

The chloride concentrations averaged 37.6 mg/m^3 (25.6 ppm) and had a maximum of 138.3 mg/m^3 (94.1 ppm), a minimum of 4.3 mg/m^3 (2.9 ppm), and a standard deviation of 36.7 mg/m^3. The fluoride concentrations averaged 0.9 mg/m^3 (0.3 ppm) and had a maximum of 2.1 mg/m^3 (2.6 ppm), a minimum of 0.2 mg/m^3 (0.3 ppm), and a standard deviation of 0.3 mg/m^3. The gas chromatograph analysis for the C_1 to C_6 hydrocarbons revealed that their amounts varied from sample to sample and day to day. Over the three test periods, the sums of the C_1 to C_6 hydrocarbons ranged from 1.8 to 1423 mg/m^3 and averaged 18mg/m^3, 476 mg/m^3, and 70 mg/m^3 in the first, second, and third tests, respectively.

Residue Effects on Actual Landfill--

The residue was dumped in a large, deep, open pit on the plant site which will be covered when it is full.

The chemical analysis of the original residue samples and the simulated leachate filtrate are presented in the following discussion of the EPA Level One analysis.

Plant Areas--

To sample the ambient air inside the plant, the respirable fraction personnel sampler was mounted on the ram loader so that the effects of lifting the refuse and then dumping it into the loading hopper could be determined.

TABLE 52. MARYSVILLE SUMMARY OF STACK EMISSIONS FOR JULY TESTS

	Emissions		
Parameter	Maximum	Average	Minimum
Particulate* g/m^3 (gr/SCF)	.253 (.111)	.111 (.049)	.075 (.033)
Particulate g/m^3 (gr/SCF)	.212 (.093)	.091 (.040)	.064 (.028)
Particulate Size (μm)	29	0.3	<0.3
Chloride mg/m^3 (ppm)	136 (94)	79 (54)	9.3 (6.4)
Fluoride mg/m^3 (ppm)	2.0 (2.5)	.9 (1.1)	.3 (.4)
NO_x mg/m^3 (ppm)	239 (161)	59 (40)	11 (7.4)
SO_x mg/m^3 (ppm)	82 (31)	15 (5.6)	<13 (<5)
Hydrocarbons† mg/m^3 (ppm)	1400 (2136)	475 (724)	13.7 (20.9)
O_2 Percent	18.5	14.3	5.4
CO_2 Percent	10.5	9.7	7.2
CO mg/m^3 (ppm)	>1000 (>868)	279 (242)	20 (17)
H_2O Percent	16.4	14.5	13.3

* Corrected to 12% CO_2.

† as CH_4.

TABLE 53. MARYSVILLE SUMMARY OF STACK EMISSIONS FOR APRIL, JULY, AND AUGUST TESTS

	Field test											
	Test 1: April 24-28, 1978				Test 2: July 7-17, 1978				Test 3: August 21-25, 1978			
Emissions (units)	Max	Avg	Min	Std Dev	Max	Avg	Min	Std Dev	Max	Avg	Min	Std Dev
Particulate (gr/SCF)*		Not Isokinetic			0.111	0.049	0.033	0.024	0.133	0.088	0.060	0.027
Particulate (g/m^3)*					0.253	0.111	0.075	0.054	0.303	0.201	0.137	0.061
Chlorides (mg/m^3)	23.0	13.9	5.8	7.1	136	78.6	9.3	49.7	31.7	11.4	4.2	8.6
Fluorides (mg/m^3)	0.7	0.5	0.2	0.2	2.0	0.9	0.3	0.6	1.7	1.0	0.7	0.3
O_2 (percent)	17.8	14.0	10.7	1.7	18.5	14.3	5.4	2.8	19.4†	15.9	12.4	1.9
CO_2 (percent)		No Data			10.5	9.7	7.2	1.01	9.0	5.6	3.4	1.8
CO (mg/m^3)	>1000	148	26	27	>1000	279	20	129	363	108	8	93
NO_x (mg/m^3)	191	64	<10	38	239	59	11	47	143	33	<10	34
SO_x (mg/m^3)	37	16	<13	7.0	82	15	<13	21	56	9.0	<13	10
Particulate size (μm)#		No Data			29	0.3	<0.3	--	27	0.7	<0.7	--
Hydrocarbons (mg/m^3)ϕ	105	17.9	1.8	--	1400	475	13.7	--	204	70	9.1	--
Opacity (percent)		No Data		--		No Data		--	42	--	15	--
H_2O (percent by volume)	14.4	8.4	1.8	--	16.4	14.5	13.3	--	14.4	9.6	1.8	--
Flue gas temperature (°F)	150	195	227	--	237	280	291	--	217	326	459	--
Flue gas flow (SCFM)	1790	2195	3155	--	6830	2870	2210	--	2490	2250	1700	--
Flue gas flow (ACFM)	3765	2773	2205	--	9350	4075	3100	--	3920	3445	2235	--

* Corrected to 12 percent CO_2
† During charging hours only
# Average is mass mean diameter
ϕ Average CH_4-C_4H_{10}

TABLE 54. MARYSVILLE EMISSION RATES FOR JULY TEST

Pollutant	Emission rate			
	Maximum	Average	Minimum	lb/ton refuse charged
Particulate	0.111 gr/SCF*	.049 gr/SCF*	.033 gr/SCF*	2.01
SO_x	31 ppm	15 ppm	<5 ppm	.44
NO_x	125 ppm	30 ppm	6 ppm	1.19
CO	>1000 ppm	240 ppm	17 ppm	5.81
HC	2285 ppm	765 ppm	21 ppm	10.4
Lead		624 $\mu g/m^3$		0.02

* Corrected to 12 percent CO_2.

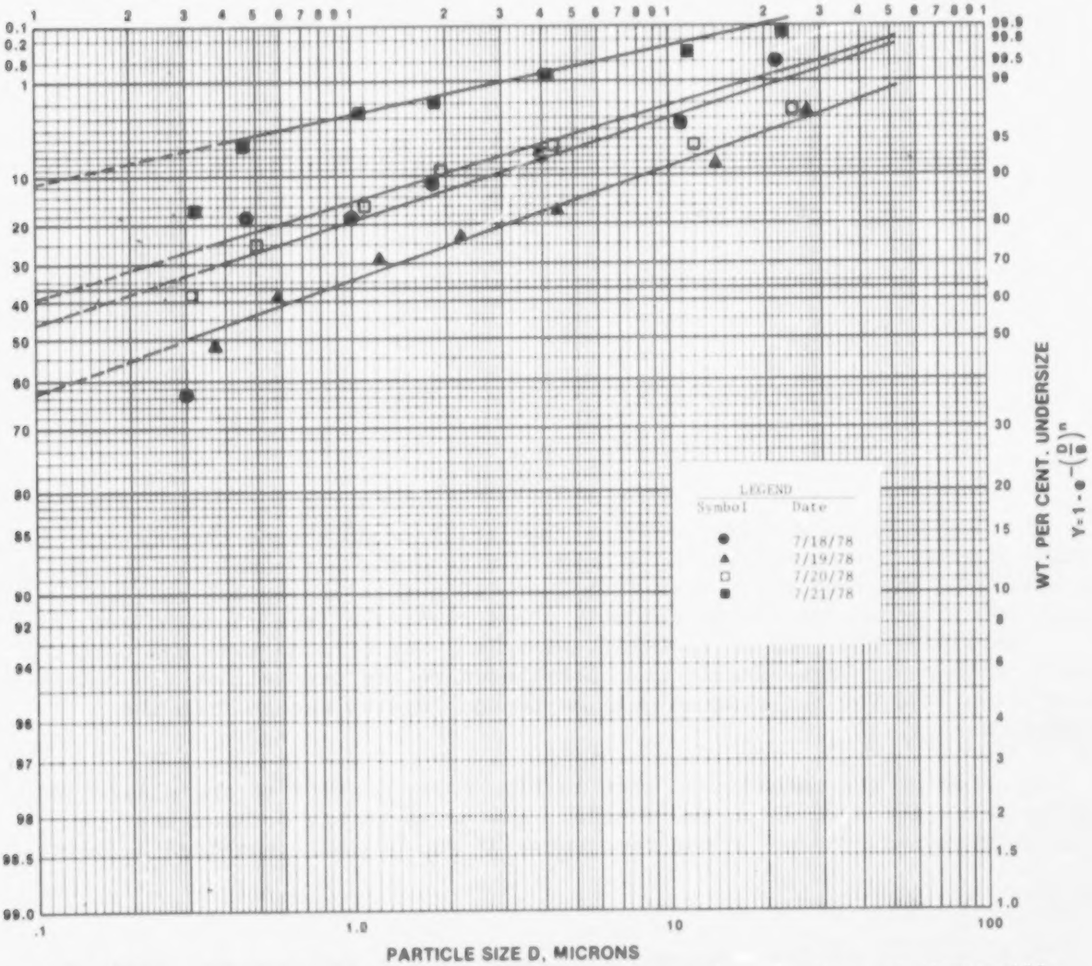


Figure 70. Particulate size distribution of stack emissions at Marysville.

No microbiological tests were conducted since the refuse burned included only wood and paper.

As summarized in Table 55, the dust concentrations averaged 1.17 mg/m^3 and had a standard deviation of 0.66 mg/m^3. Although the average dust concentrations were higher than those at North Little Rock, they were below objectionable levels. The higher dust levels at the Marysville plant were attributed to the low moisture content and other characteristics of the refuse burned.

TABLE 55. MARYSVILLE DAILY IN-PLANT FUGITIVE DUST CONCENTRATIONS FOR JULY AND AUGUST TESTS

Date	CONCENTRATION (mg/m^3)
7/19	1.16
7/20	0.60
7/21	0.83
8/22	0.12
8/23	2.39
8/24	1.93
Average	1.17
Standard Deviation σ =	0.66

The carbon monoxide levels inside the facility and around the outside primary chamber were monitored by a hand-held Ecolyzer air sampler. Inside the building, the readings varied from 20 to 40 ppm in the boiler-chiller area, from 15 to 30 ppm in the assembly plant area, and from 25 to 30 ppm in the areas behind the running fork-lift vehicle. The outside readings ranged from 4 to 10 ppm. These levels were attributed to the trucks that frequently passed alongside the building as well as to the gaseous escape from the primary chamber.

As shown by the noise-level plot in Figure 71, no area in the plant had a noise level above 90 dB on the A band. The noise levels outside the plant were not measured because of the remoteness of the nearest inhabited buildings.

EPA Level One Analysis

This section briefly discusses the EPA Level One analysis and presents the pollutants detected in this analysis.

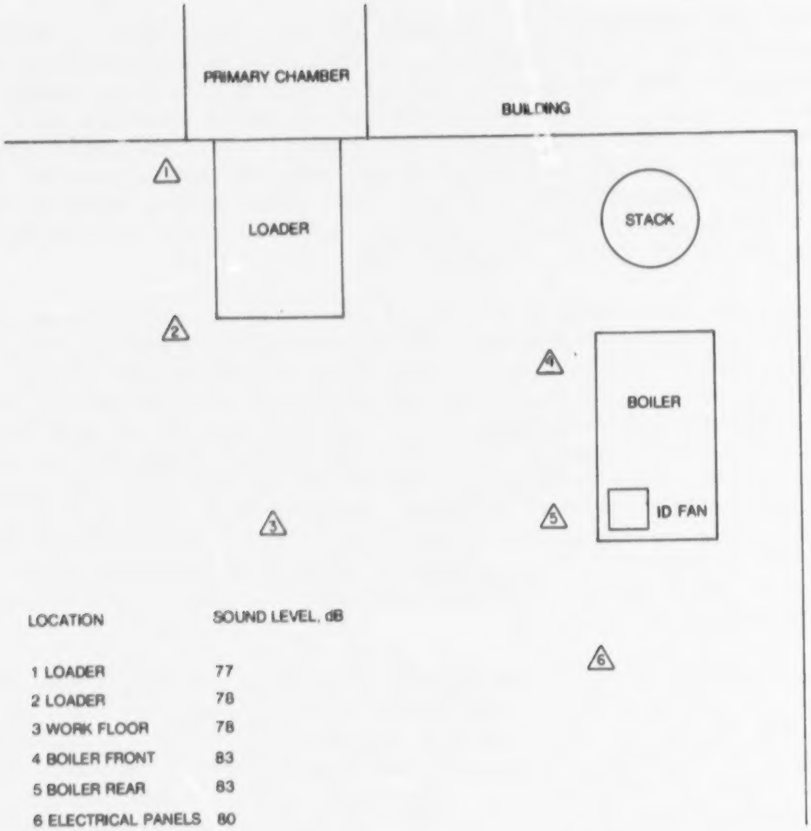

PRIMARY CHAMBER
BUILDING
LOADER
STACK
BOILER
ID FAN
1
2
3
4
5
6
LOCATION
SOUND LEVEL, dB
1 LOADER 77
2 LOADER 78
3 WORK FLOOR 78
4 BOILER FRONT 83
5 BOILER REAR 83
6 ELECTRICAL PANELS 80

Figure 71. In-plant noise-level plot for Marsyville facility.

The EPA Level One tests were run during the week of July 17 to 21, 1978. The ambient air tests were run as follows: the particulate size distribution test was run for a 24-hr period over the 18th and 19th, the filter for chemical analysis was installed for a 24-hr period on the 21st, sorbent trap Nos. 3 and 5 were installed for a 24-hr period over the 19th and 20th, and the grab sampler was installed on the 20th. The stack sorbent trap tests were run as follows: trap No. 1 on the 18th, trap No. 4 on the 19th, and trap No. 2 on the 20th. The grab sample was taken on the 20th. The Method 5 filter and impinger tests, run No. 6 on the data sheets, were taken on the 20th.

Stack Emissions--

The flue gases in the exhaust stack were periodically sampled as follows for various types of analyses to reveal the organic and inorganic contaminants in the gases exiting to atmosphere: (1) by the filter in the modified EPA Method 5 train, (2) by the sorbent trap installed with the filter in the Method 5 train, (3) by the impingers in the Method 5 train, and (4) by Tedlar grab bags.

In the gas chromatography analysis of the filter samples for organic contaminants, no C_7 - C_{12} hydrocarbons, chlorinated hydrocarbons, or organic sulfur compounds were found with their respective detection thresholds being 42, 21, and 40 $\mu g/m^3$. Similarly, infrared analysis detected none of these contaminants. In the atomic absorption analysis for inorganic contaminents, arsenic, mercury, and antimony were found with concentrations of 15.63, 1.25, and 2.41 $\mu g/m^3$, respectively. In addition, spark source mass spectrometry analysis found manganese, zinc, cadmium, and lead with concentrations of 40, 400, 26.5, and 66.25 $\mu g/m^3$, respectively.

The sorbent trap resin for each of three tests was analyzed as follows: in the gas chromatography analysis for C_7 - C_{12} hydrocarbons, nonane (C_9) was found in the first test with a concentration of 104 $\mu g/m^3$; octane (C_8) and dodecane (C_{12}) were found in the second test with concentrations of 2275 and 100 $\mu g/m^3$, respectively; undecane (C_{11}) and dodecane (C_{12}) were found in the third test with each having a concentration greater than 1360 $\mu g/m^3$; chlorinated hydrocarbon tetrochloreothane was found in the first and second tests with concentrations of 29 and 30 $\mu g/m^3$, respectively; and sulfur compounds were not detected in any of the three tests with a detection threshold of 3 $\mu g/m^3$. The infrared ayalysis detected the following functional groups: weak C=O, weak NH_2^+ NH_3^+ or N=N stretch, weak C=C and/or C=N stretch, and medium C-OH and/or S=O stretch.

Gravimetric analysis of the liquid chromatography fractions and subsequent infrared analysis found additional weak C=C and weak C-OH or R-D-R stretch compounds in the third test. Low-resolution mass spectrometry analysis detected aromatic compounds and other general compounds such as aldehydes, alcohols, and amines in the third test. Atomic absorption analysis found arsenic and mercury with concentrations of 1.57 and 1.02 $\mu g/m^3$, respectively, in the third test. Finally, spark source mass spectrography analysis detected lead in the first test; fluorine, cadmium, barium, and chromium in the second test; but no elements in the third test.

In the atomic absorption analysis of the impinger solutions, no mercury or antimony was detected in any of the three impingers, but 0.32 $\mu g/m^3$ of arsenic was found in the first impinger. In the spark source mass spectrometry analysis, barium, sulfur, chlorine, bromide, and tin were found in the second and third impingers. In the inorganic analysis for ammonia (NH_3) and prussic acid (HCN) compounds, no HCN was detected, but 3.44 and 7.60 ppm concentrations of NH_3 were found in the second and third impingers, respectively. In the chemical analysis for carbonyl compounds, 80.1 and 9.0 mg/ℓ of these compounds were found in the impinger solutions for the July 19 and July 20 tests, respectively.

The Tedlar bag samples were analyzed for hydrogen sulfide (H_2S) and carbonyl sulfide (COS) by spark source mass spectrometry. With detection levels of 10 ppm for H_2S and 25 ppm for COD, neither of the sulfides was found.

Residue and Leachate--

In the gas chromatography analysis of the residue samples to detect C_7 - C_{12} hydrocarbons, chlorinated hydrocarbons, and sulfur compounds with detection thresholds of 5.7, 3.0, and 8.0 μg/g, respectively, only 1,1,2-Trochlorethane was detected. Infrared analysis did not find any carbonyl functional groups. Atomic absorption analysis detected arsenic and antimony with concentrations of 7.96 and 0.80 $\mu g/m^3$, respectively, but no mercury. The spark source mass spectrometry analysis detected many elements in high concentration, the most significant being phosphorus, chromium, iron, copper, zinc, and tin each with concentrations greater than 1000 μg/g, and lead with a concentration of 5000 μg/g. Table 56 presents the residue analysis results.

TABLE 56. MARYSVILLE RESIDUE ELEMENT CONCENTRATIONS

Component	Concentration μg/g
Decane	ND*
Undecane	ND
Arsenic	7.96
Antimony	.80
Sulfur	1000
Chlorine	100
Potassium	High#
Phosphorus	High
Chromium	High
Iron	High
Zinc	High
Copper	High
Fluorine	1000
Tin	1000
Molybdenum	High
Barium	10
Lead	5000
Cadmium	High
Bromide	0
Boron	1000
Mercury	0

* Not detectable.

# High > 1000.

In the chemical analysis of the leachate filtrate from the run with only distilled water with a 5.5 pH, the pH, conductivity, alkalinity, hardness, and dissolved solids increased. In addition, from less than 1.0 mg/ℓ, sulfate increased to 68 mg/ℓ; from less than 0.1 mg/ℓ, boron increased to 2.6 mg/ℓ; and from less than 1.0 μg/ℓ, antimony, lead, and chromium increased to 18.7, 1.3, and 3280 μg/ℓ, respectively. In the analysis of the filtrate from the run with both distilled water and the phosphate buffer to lower the pH to 5.0, the pH had a small increase while the conductivity, alkalinity, and dissolved solids increased more than they had in the former run. In addition, the chloride, bromide, and boron concentrations increased while the sulfate and fluoride concentrations decreased. The phosphate buffer caused high levels of phosphate that interfered with the ortho and total phosphate test. The results are shown in Table 57.

TABLE 57. MARYSVILLE RESIDUE LEACHATE PARAMETER AND COMPONENT VALUES

		Water Blank	Test 1	Phosphate Buffer Test 2
pH		5.52	10.24	6.2
Conductivity	umhos	2.78	379.00	3700
Alkalinity	mg/ℓ	1.10	78.10	232
TKN	mg/ℓ	6.95	2.59	7.05
Hardness	mg/ℓ	2.00	112.30	<0.1
TOC	mg/ℓ	3.10	5.00	<1
Ortho-Phosphate	mg/ℓ	0.005	0.002	1230
Total Phosphate	mg/ℓ	0.01	0.063	1360
Sulfide	mg/ℓ	<0.002	<0.002	< .003
Chloride	mg/ℓ	ND	1.51	43
Acidity	mg/ℓ	5	ND	1938
Total Dissolved Solids	mg/ℓ	<1	236	6012
Ammonia as N	mg/ℓ	0.216	0.170	0.076
COD		ND	ND	52.5
Sulfate	mg/ℓ	<1.00	68.00	0.19
Bromide	mg/ℓ	<0.100	<0.100	0.64
Fluoride	mg/ℓ	0.058	0.662	0.363
Boron	mg/ℓ	<0.1	2.6	65.6
Mercury	μg/ℓ	<0.1	<0.1	-
Cadmium	μg/ℓ	<1	<1	-
Antimony	μg/ℓ	<1.0	18.7	-
Lead	μg/ℓ	<1	1.3	-
Chromium	μg/ℓ	<1	3280	-
Arsenic		ND	ND	-
MBAS	mg/ℓ	-	-	.121
Phenols	mg/ℓ	-	-	.080
Cyanide	mg/ℓ	-	-	.002

ND = None detected

Outside Ambient Air--

The ambient air outside the plant was sampled upwind and downwind by the high-volume sampler equipped in turn with the filter and the Anderson head impactor, by the sorbent trap enclosed in the weatherproof box, and by the Tedlar bags.

The positioning of the upwind and downwind sample sites, each about 91m (300 ft) from the exhaust stack, posed the following difficulties: On the upwind side, the nearest available power outlet was such that the extension cord extended to a corner of the plant warehouse. While this site was the proper direction and distance from the stack, it was not an optimum sampling position since it was beside a road where heavy truck traffic frequently generated dust and exhaust fumes. On the downwind side, the plant building extended some 97.5m (320 ft) from the stack so that the downwind site had to extend a total of 189m (620 ft) from the stack to provide an uninterrupted 91m (300-ft) distance between the stack and the site.

In the gas chromatography analysis of the filters, no C_7 - C_{12} hydrocarbons, chlorinated hydrocarbons, or sulfur compounds were found with detection thresholds of 10, 1.0, and 1.0 $\mu g/m^3$, respectively. Similarly, infrared and gravimetric analyses did not detect any of these compounds. In the atomic absorption analysis to detect arsenic, antimony, and mercury with a detection threshold of 0.1 $\mu g/m^3$, only arsenic was found in the upwind filter and just at the threshold level. Spark source mass spectrometry revealed no measurable difference between the upwind and downwind filters.

The size distribution analysis of the particulates captured on the three stages of the impactor is summarized in Table 58.

TABLE 58. MARYSVILLE AMBIENT AIR PARTICULATE SIZE DISTRIBUTIONS

	Particle Size μ	Weight gm	Concentration μg/m^3
Upwind			
	>7	0.0242	29.7
	1.1 - 7	0.0157	19.3
	<1.1	0.0287	35.2
	TOTAL		84.2
Downwind			
	>7	0.0185	22.7
	1.1 - 7	0.0149	18.3
	<1.1	0.0220	27.0
	TOTAL		68.0

In the gas chromatography analysis of the resin sorbent trap, no C_7 - C_{12} hydrocarbons, chlorinated hydrocarbons, or sulfur compounds were found with detection thresholds of 10, 1, and 3 $\mu g/m^3$, respectively. Similarly, infrared analysis did not detect any of these compounds. In the atomic absorption analysis to detect arsenic, antimony, and mercury, only 0.3 $\mu g/m^3$ of mercury was found in the upwind filter. In the spark source mass spectrometry analysis for metallic elements with a detection threshold of 0.1 $\mu g/m^3$, none of the elments were found in the downwind resin, but the following elements and their concentrations were found in the upwind resins: chromium, 7.00 $\mu g/m^3$; copper, 0.14 $\mu g/m^3$; zinc, 0.14 $\mu g/m^3$; and tin, 4.20 $\mu g/m^3$.

In the chemical analysis of the Tedlar bag samples to detect carbonyl-oxygen-sulfur compounds, H_2S, organic sulfur compounds, NH_3, HCN, and $(CN)_2$, none of the pollutants were found.

Summary--

Of the major contaminants detected in the EPA Level One analysis of the liquid, gaseous, and solid effluents caused by the plant, antimony, arsenic, mercury, and heavy organic compounds were found consistently in small amounts. Other metals such as lead, cadmium, chromuim, and barium were found occasionally in small amounts. Table 59 summarizes the air emissions findings and Table 60 quantifies the high values found in the emissions filters as given in Table 59.

Economic Evaluation

The Rockwell International Truck Axle Division in Marysville, Ohio, uses a standard cost accounting system, which is commonly employed by commercial manufacturers. With such a system, normal (standard) cost rates are established for units of material, labor, and overhead. The rates for these three categories are determined by analyzing the unit prices paid for materials used in production as well as the unit labor costs and the indirect operating costs.

The Marysville plant accounting records are maintained on an accrual basis of accounting whereby each revenue and expense is recorded during the period when the revenue is earned or the expense is incurred.

Although the accounting records reflect various operating cost areas, these cost areas are used to account for the normal commercial activity of the plant. Consequently, a separate cost area for operating the incinerator-heat recovery facility was not established. The operating costs of the facility, therefore, are intermingled with other types of direct and indirect cost accounts.

The capital costs incurred for the incinerator-heat recovery facility, such as those for the construction of the facility shell and the acquisition of major equipment items, have been capitalized and are reflected in the asset accounts of the plant. These assets, therefore, were subjected to annual depreciation rather than charged as operating expenses at the time of construction or acquisition.

The Truck Axle Division maintains an accounting system which yields adequate financial information for managing its daily commercial activities. However, because of the lack of specific accounts or cost centers for the incinerator-heat recovery facility, SYSTECH maintained independent records for the operating and maintenance costs applicable to the facility operation. In addition, with the Truck Axle Division comprising only one operating division among many within the Rockwell International Corporation structure, many applicable costs of the facility such as the true financing costs, other overhead items such as insurance, and a share of professional fees could not be determined. Such costs are allocated to the Truck Axle Division without identifying the specific cost area. However, the accounting of such costs to the facility should be immaterial because of the facility's relatively little part within the plant.

TABLE 59. MARYSVILLE SUMMARY OF ELEMENTS DETECTED IN EPA LEVEL ONE ANALYSIS

	Element Source									
	Ambient Air				Stack emissions					
	Filter		Sorbent trap		Method 5	Sorbent trap			Impingers	
Element	Upwind	Downwind	Upwind	Downwind	filter	1	2	3	1	2 & 3
Li	N	N	N	N	N	N	N	N	N	N
Be	N	N	N	N	N	N	N	N	N	N
B	*	*	N	N	*	*	*	*	D	D
F	N	N	N	N	N	N	D	N	N	N
Na	*	*	*	*	*	*	*	*	*	*
Mg	*	*	*	*	*	*	*	*	N	N
Al	N	N	N	N	N	N	N	N	N	N
Si	*	*	*	*	*	*	*	*	D	N
P	*	*	*	*	*	*	*	*	N	N
S	*	*	*	*	*	*	*	*	D	D
Cl	*	*	*	*	*	*	*	*	N	D
K	*	*	D	D	*	N	N	N	N	N
Ca	*	*	D	D	*	N	N	N	N	N
Sc	N	N	N	N	N	N	N	N	N	N
Ti	D	D	N	N	N	N	N	N	N	N
U	N	N	N	N	N	N	N	N	N	N
Cr	N	N	N	D	N	N	D	N	N	N
Mn	D	D	N	N	D	N	N	N	N	N
Fe	*	*	*	*	*	*	*	*	N	N
Co	N	N	N	N	N	N	N	N	N	N
Ni	N	N	N	N	N	N	N	N	N	N
Cu	N	N	N	D	N	N	N	N	N	N
Zn	N	N	N	D	D	N	N	N	N	N
Ga	N	N	N	N	N	N	N	N	N	N
Ge	N	N	N	N	N	N	N	N	N	N
Se	N	N	N	N	N	N	N	N	N	N
Br	N	N	N	N	N	N	N	N	N	D
Rb	N	N	N	N	N	N	N	N	N	N
Ba	N	N	D	D	N	N	D	N	N	N
Pb	D	D	N	N	D	D	N	N	N	N
Sn	N	N	N	D	N	N	N	N	N	D
Cd	N	N	N	N	D	N	N	N	N	N

*	Test interference
N	Not detected
D	Detected

TABLE 60. MARYSVILLE SUMMARY OF ELEMENTS DETECTED IN STACK EMISSION FILTERS

Element	Emission rate	
	Concentration in gas ($\mu g/m^3$)*	Emission factor g/Mg of refuse†
Silicon	2.95	.042
Iron	520.	7.45
Aluminum	2,202.	31.5
Sodium	13,839.	198.0
Calcium	1,749.	25.0
Potassium	450.	6.44
Magnesium	640.	9.17
Lead	624.	8.93
Zinc	2,724.	39.0
Cadmium	428.	6.14
Beryllium	0.09	.0014
Titanium	0.419	.0060
Chromium	1.66	.0237
Copper	19.3	.277
Nickel	1.78	.0255
Manganese	11.4	.164
Lithium	2.10	.030
Antimony	1.69	.0243
Boron	98.1	1.41
Tin	3.33	.0477
Vanadium	2.30	.033

* Concentrations based on a composite of five filters from July test period.

† g/Mg ÷ 500 = lb/ton

Capital Costs and Their Financing--

The capital costs incurred for the facility construction were ascertained by identifying payments made to major contractors and suppliers, by examining supporting purchase order agreements, and by acquiring information from the plant's accounting personnel. The source documents were reviewed to determine whether the expenditures were (1) properly chargeable to the facility, (2) properly classified as capital expenditures, and (3) were materially accurate for reclassification per EPA guidelines and cost centers. The resultant costs were divided into those associated with just the incineration system and those identified with the heating and cooling system modifications to accommodate the incineration system.

The plant accounting personnel were not certain whether all capital costs had been identified as capital assets in the accounting records. The accounting records showed that $509,949 had been expended as the total capital costs for the facility. The costs incurred in modifying the building and the plant's existing heating and air conditioning systems amounted to $380,616 of this total. In addition, the new boiler cost $49,245. Therefore, the cost of the incineration system was $80,088. In addition, since an ash removal and magnetic separation conveyor had been disposed of, the capital cost had to be reduced to reflect the capital cost of the operating facility. With the conveyor cost estimated at $4,379, the incineration capital cost was therefore reduced to a final figure of $75,709.

According to the plant accounting personnel, the land is valued at approximately $3,000. This amount was excluded from the depreciable asset base which is further discussed under the operating and maintenance costs.

Table 61 presents the capital cost breakdown which generally agrees with the EPA cost categories. The site preparation costs are included in the construction costs since they could not be distinguished from the other construction costs in the plant accounting records.

TABLE 61. MARYSVILLE CAPITAL COSTS*

	Incineration	Heat Recovery
Land	$ 1,000	$ 2,000
Site preparation	†	†
Design		12,500
Construction	7,000	82,166
Real equipment	69,302	335,081
Total capital investment	77,302	432,647

* Based on 1977 dollars.

† Site preparation costs were not identified in Rockwell International Corporation accounting records.

After a review of the incurred costs, the total capital cost was distributed among the four cost centers: the three functional areas, namely receiving, incineration, and heat recovery, and the general plant. Besides this distribution, Table 62 also distributes the total capital cost among just the three functional areas with the $88,364 for the general plant allocated to each of the functional areas according to their proportional amounts in the first distribution. The general plant cost includes the land value and the expenditure for the construction of the facility shell.

TABLE 62. MARYSVILLE CAPITAL COST ALLOCATIONS BY COST CENTER*

Cost center	Capital costs	Reallocated capital costs
Receiving	$ 652	$ 789
Incineration	63,263	76,523
Heat recovery	357,670	432,638
General plant	88,364	
Total	$509,949	$509,949

* Based on 1977 dollars.

Then for each depreciable item, Table 63 lists the initial cost, including as applicable the freight, insurance, and installation costs, the related cost center, and the estimated useful life. The estimated useful lives, namely 12 years for real equipment items and 4 to 35 years for the respective general plant items, were used in computing the annual depreciation expenses which are presented under the operating and maintenance costs.

TABLE 63. COST, COST CENTER, AND ESTIMATED USEFUL LIFE FOR EACH MAJOR EQUIPMENT ITEM IN MARYSVILLE FACILITY*

Equipment item	Cost**	Cost center	Useful life (yr)
9 Starter coils, starter combination	$ 3,033	General plant	12
Plant shell	65,779	General plant	35
Bussway	665	General plant	35
Internal work	12,500	General plant	35
1 KH model 1280/72 pyrolysis system	49,195	Incineration	12
1 Ash removal ram system	11,183	Incineration	12
1 Primary chamber burner	2,006	Incineration	12
1 Primary chamber water spray	879	Incineration	12
TP-4 Turbo motor	573	Heat recovery	12
1 Low-pressure boiler	49,245	Heat recovery	12
Heating and cooling†	307,852	Heat recovery	12
1 RAM recycle	652	Receiving	12
Total#	$509,949		

* Based on 1977 dollars.

** Includes cost of freight, insurance, and installation.

† Contracted total cost of cooling tower, piping, and absorption chiller.

# Initial capital investment less cost of land.

The capital cost of the incinerator-heat recovery facility was financed through retained earnings. The Rockwell International home office allocates such by internally generated funds.

The corporate cost of capital, which is theoretically a weighted mixture of the cost of debt, equity, and internal financing, is a reasonable measurement of what it costs a corporation to make capital investment decisions such as those for the Marysville facility. The Rockwell International cost of capital approximates 10 percent. This percentage is subsequently reflected in this report under the interest costs within the operating and maintenance costs.

Operating and Maintenance Costs--

The major operating costs for the facility operation are labor, utilities, materials, interest, and depreciation. As mentioned previously, separate cost centers are not maintained for the facility operation. Consequently, for this evaluation, the plant engineer estimated the manpower requirements, and SYSTECH estimated the manpower for the cost centers by observing the tasks performed by the facility personnel.

The natural gas consumption of the facility was determined by taking the difference between the April 24 and August 25, 1978, readings on a gas meter which only measures the gas flow to the facility. Then the corresponding cost for this period was extropolated to a year to determine the annual gas cost allocation to the incineration cost center.

The electricity costs were allocated to the cost centers according to the ammeter readings and timers on the various motors.

Since water is only used for flame quenching, the operating cost for water was allocated to the incineration cost center. The weter consumption rate was determined by measuring the water quench flow rate during a down period and by timing the periods when the quench was spraying between April 24 and August 25, 1978.

The chemical costs were obtained from records maintained by the plant engineer. Since these chemicals are used to treat the boiler water, the entire cost of chemicals was allocated to the heat recovery cost center.

After the foregoing parameter data were extrapolated to represent a 16-hour day, 250-day year, the annual parameter data were distributed among the cost centers of the three functional areas as shown in Table 64. Table 65 presents the unit cost data which was used in conjunction with the operating parameter data to derive the estimated operating costs. The unit costs were obtained from records maintained by the plant engineer.

A comprehensive economic evaluation was based on the actual operating conditions, i.e., firing at half the rated capacity, a two-shift operation, and a system efficiency of 42 percent.

The preparation of the evaluation required estimating the maintenance costs and including the interest and depreciation costs to make the evaluation complete and reasonable.

The annual maintenance cost was estimated by taking 5.5 percent (the IRS guideline for maintenance costs) of the total depreciable assets in Table 63. In addition, the annual cost for equipment replacement was added to this estimate. As stated above, the corporate cost of capital is 10 percent. This percentage is likely used to represent the interest that could be acquired if capital allocated for plant and equipment expenditures were rather invested in a revenue-providing project. Consequently, to compute the total annual interest, the net book value (cost less accumulated depreciation) of each of the items in Table 63 was multiplied by 10 percent over the respective useful lives as given in this table. In the computation of the annual depreciation cost of the items in Table 63, a straight line depreciation was used with 12 years as the life for the real equipment items and 4 to 35 years for the respective general plant items.

TABLE 64. MARYSVILLE OPERATING PARAMETER VALUES FOR COST CENTERS

Parameter	Total	Cost center Receiving	 Incineration	 Heat Recovery
Operating schedule:	16 hr/day			
Incinerator	250 days/year			
Heating	128 days/year			
Cooling	122 days/year			
Refuse feed rate:				
Mg/hr	0.28			
Mg/yr	875			
Heat recovered:				
MJ/day	23,025			
Staffing:				
General helper	1	50%	40%	10%
Natural gas consumption:				
kℓ/day	419		419	
Electric power demand:				
kwh/day	113.1	6.2	30.2	74.9
Water consumption (ℓ/day)	2611		2611	
Sewer flow (ℓ/day)	none	----	----	----
Chemicals (NC-1) (ℓ/yr)	28.4			28.4

TABLE 65. MARYSVILLE UNIT COST DATA*

Salary rates (annual, FY 78):	
General helper	$14,500
Employee benefits rate	$5,800
Natural gas	$0.091/kℓ
Electricity rate	$0.0282/kwh
Water rate	$0.24/1000ℓ
Sewer	†
Chemical (NC-1) costs	$2.30/ℓ

*Based on costs incurred in 1978.
†On-site disposal (septic system).

Then the annual costs for maintenance, interest, and depreciation, as computed above, were combined with the data in Tables 64 and 65 to derive the projected annual operating and maintenance costs by the four cost centers. Table 66 lists the resultant costs. In the development of this table, the salary and employee benefits related to residue removal were included under the salaries and employee benefits cost categories. While other overhead costs could not be ascertained, they should be minimal. Except for interest and depreciation, the cost categories in Table 66 generally agree with those in the EPA accounting format.

TABLE 66. MARYSVILLE PROJECTED ANNUAL OPERATING AND MAINTENANCE COSTS PER COST CENTER*

Cost classification	Total cost	Cost Center			
		Receiving	Incineration	Heat recovery	General plant
Salaries	$ 14,500	$ 7,250	$ 5,800	$ 1,450	
Employee benefits	5,800	2,900	2,320	580	
Fuel	9,914		9,914		
Water and sewer	163		163		
Electricity	829	45	235	549	
Maintenance	15,004	828	3,498	5,818	$ 4,860
Chemicals	65			65	
Interest	24,480	687	2,918	16,592	4,283
Depreciation	34,815	1,255	5,300	24,499	3,671
Sub total	$105,570	$12,965	$30,148	$49,553	$12,904
General plant allocation:		3,045	4,084	5,775	
Total	$105,570	$16,010	$34,232	$55,328	

*Based on 1978 dollars.

As shown in Table 67, the annual costs in Table 66 were also broken down into fixed and variable costs. All costs in the salaries and employee benefits categories were variable since all facility employees at Marysville would be assigned to other plant areas during facility shutdowns.

TABLE 67. MARYSVILLE ANNUAL FIXED AND VARIABLE OPERATING AND MAINTENANCE COSTS*

Item	Total	Fixed	Variable
Salaries	$ 14,500		$14,500
Employee benefits	5,800		5,800
Fuel	9,914		9,914
Electricity	829		829
Water and sewer	163		163
Maintenance†	15,004	$ 7,502	7,502
Chemicals	65		65
Interest	24,480	24,480	
Depreciation	34,815	34.815	
Total costs	$105,570	$66,797	$37,234

* Based on 1978 dollars.

† Since some maintenance continues during plant shutdowns, one-half the estimated annual maintenance cost was assumed to be fixed.

Revenues (Savings)--

Although the incinerator-heat recovery facility was installed to provide an assured energy supply for the plant's heating and air conditioning systems, and not to produce revenue by itself, it indirectly produces a revenue by eliminating the costs previously expended for the propane used during the winter and for the electricity used during the summer.

During the three test periods, the average heat recovery rate was 23,025 GJ/day (21,825 MBtu/day). With estimated heating and cooling seasons of 120 and 70 days, respectively, and with the previous propane and electricity costs of $0.00404 and $0.00769 per MJ ($4.26 and $8.11 per MBtu), respectively, the facility yields an annual savings, or annual revenue equivalent, of $23,557.

Net Operating Cost--

With $105,570 as the projected annual operating and maintenance cost and $23,557 as the estimated annual energy savings (revenues) and $27,500 as the annual disposal cost savings, the net annual operating cost will be $54,513. Table 68 compares the costs, savings (revenues), and net costs or savings per unit of refuse processed.

TABLE 68. MARYSVILLE NET OPERATING COST BY SYSTEM FUNCTION*

	Incineration			Incineration and Heat recovery		
	($/yr)	($/Mg)	($/ton)	($/yr)	($/Mg)	($/ton)
Operating and maintenance	(34,232)		(28.53)	(105,570)		(87.98)
Disposal savings	27,500		22.95	27,500		22.95
Energy savings				23,557		19.63
Net savings (cost) of operation	(6,732)	(5.92)	(5.61)	(54,513)	(47.93)	(45.43)

* Based on 1978 dollars, 1200 tons annually.
Operating cost includes interest and depreciation.

Summary--

With the facility requiring an initial capital investment of $509,949, its anticipated annual operation will cost $54,513 or $47.93 per Mg ($45.43 per ton) of refuse processed. In comparison with the net cost per unit of refuse processed the cost for landfill disposal is $25.30/Mg ($22.95/ton).

The after tax positive cash flow would be $85,400 the first year and $7,600 for each year thereafter. The first year value includes all of the 10 percent investment tax credit and the additional 10 percent energy credit effective in 1978.

SECTION 5

OPERATING COST PROJECTIONS

INTRODUCTION

This section projects (1) the optimum annual operating and maintenance costs for the North Little Rock and Marysville facilities and (2) the capital costs and the net annual operating costs for municipal and industrial plants in general. While the preceding section presents the annual operating and maintenance costs for the two evaluated facilities, these costs were themselves projections based on limited monitoring periods of as-operated conditions during the early operational phases of the facilities. Therefore, to represent the evaluated facilities at maximum design capabilities, this section presents the costs on the basis of optimum operating conditions. In the treatment of the municipal and industrial plants in general, the net annual operating costs are presented as (1) a function of the operating percentage of rated capacity and (2) a function of refuse feed rate and shifts per week as well as of the operating percentage of rated capacity.

PROJECTED OPTIMUM ANNUAL OPERATING COSTS FOR PLANTS EVALUATED

North Little Rock Facility

The optimum operating conditions for the North Little Rock facility would be (1) a refuse feed rate equal to the design capacity of 3.6 Mg/hr (4 TPH), (2) a steam production rate of 8.181 kg/hr (18,000 lb/hr), (3) diesel fuel and gasoline usage rates proportional to the refuse feed rate, and (4) water and chemical usage rates proportional to the steam generation rate. Under these conditions and as summarized in Table 69, the total annual operating and maintenance costs would be $370,739 or $17.03/Mg ($15.45/ton) of refuse processed.

Revenues--

Table 70 presents the estimated annual revenues for the optimum operating conditions. Since the commercial tipping fees charged would remain the same, the greater revenue, as compared with the as-operated conditions, would be due to the sale of all steam produced with all flue gases passing through the boilers. The optimum operating conditions would yield a total revenue and a revenue per Mg of refuse processed that would be respectively $127,773 and $3.00 more than those produced under the as-operated conditions.

TABLE 69. NORTH LITTLE ROCK PROJECTED OPTIMUM OPERATING AND MAINTENANCE COSTS*

Item	Cost ($/yr)	Cost ($/Mg)
Salaries	$111,284	$ 5.11
Employee benefits	15,750	0.72
Fuel - no. 2 diesel	4,608	0.21
Natural gas	16,704	0.77
Gasoline	3,888	0.18
Electricity	19,237	0.88
Water and sewer	8,121	0.37
Maintenance	65,656	3.02
Replacement equipment	--	--
Residue removal	†	†
Chemicals	5,033	0.23
Interest	39,179	1.80
Depreciation	78,070	3.59
Other overhead	3,209	0.15
Total operating and maintenance costs	$370,739	$17.03

* Based on 1978 dollars.

† Cost included in salaries and employee benefit categories.

TABLE 70. NORTH LITTLE ROCK PROJECTED OPTIMUM REVENUES*

Revenues	Cost
Steam production	$280,772
Tipping fees	24,336
Total	$305,108
Per Mg of refuse processed (per ton)	$14.02 (17.07)

* Based on 1978 dollars.

Net Operating Costs--

The optimum operating conditions would yield an annual net operating cost of $65,631 since the revenue would increase to $305,108 with the operating and maintenance costs increasing to only $370,739. Table 71 presents the costs, revenues, and net costs per unit of refuse processed. Under the optimum operating conditions, the annual net operating and maintenance costs would be $65,631 or $3.01/Mg ($2.72/ton) of refuse processed.

TABLE 71. NORTH LITTLE ROCK PROJECTED OPTIMUM NET OPERATION COSTS*

	$/Mg	$/Ton
Operating and maintenance costs	(17.03)	(15.45)
Revenue	14.02	12.72
Net cost of operation	(3.01)	(2.72)

* Based on 1978 dollars.

Marysville Facility

The optimum operating conditions for the Marysville facility would be (1) firing at rated capacity of 1200 lb/hr, (2) operating at three shifts, and (3) utilizing all the recoverable heat. While these conditions would require another operator and increase the natural gas, electric, water and sewer, and chemical costs by about 50 percent, the maintenance costs would likely remain the same. The assumed constant maintenance cost was based on the fact that the smaller refractory costs (the major maintenance cost) because of less refractory damage with fewer shutdowns would offset the higher costs of other maintenance items with increased throughput.

Under the optimum operating conditions and as summmarized in Table 72, the total annual operating and maintenance costs would be $117,944 or $36.12/Mg ($32.77/ton) of refuse processed.

Revenues (Savings)--

The daily 138,167 MJ (131 MBtu) output would eliminate the need for propane energy and thereby provide a savings of $139,549.

Net Operating Costs--

While the total operating and maintenance costs would be $117,944, the twofold savings of $139,549 for energy costs and $82,620 for solid waste disposal costs would result in a net savings of $104,270. Table 73 presents the costs, savings (revenues), and net savings per unit of refuse processed.

TABLE 72. MARYSVILLE PROJECTED OPTIMUM OPERATING AND MAINTENANCE COSTS*

Item	Cost	
	($/yr)	($/Mg)
Salaries	21,750	6.66
Employee benefits	5,438	1.66
Fuel	14,871	4.55
Electricity	1,244	0.38
Water and sewer	244	0.07
Maintenance	15,004	4.59
Chemicals	98	0.03
Interest	24,480	7.49
Depreciation	34,815	10.66
Total	117,944	36.12

* Based on 1978 dollars.

TABLE 73. MARYSVILLE PROJECTED OPTIMUM NET OPERATION COSTS*

Item	Cost		
	($/yr)	($/Mg)	($/ton)
Operating and maintenance	(117,944)	(36.12)	(32.76)
Disposal savings	82,620	42.75	38.77
Energy savings	139,594	25.30	22.95
Net savings	104,270	31.94	28.96

* Based on 1978 dollars.

PROJECTED ANNUAL OPERATING COSTS FOR MUNICIPAL AND INDUSTRIAL PLANTS IN GENERAL

In order to present the effects of various operation variables on the cost of operation and to estimate the operational costs of future small modular incinerator facilities, an empirical method for estimating cost was developed as follows:

Capital Cost

The capital cost of small modular incinerator facilities is a function of the heat release rate or the capacity and the heat content of the refuse. Based on the Marysville and the North Little Rock facility costs and the vendor-estimated costs for a 180 MgPD (megagrams per day) (200 TPD) facility, the capital cost of a small modular incinerator facility with heat recovery may be estimated by the following equation

$$\text{Capital cost} = \$17{,}500 \times \text{capacity (MgPD)}$$

Figure 72 illustrates this relationship.

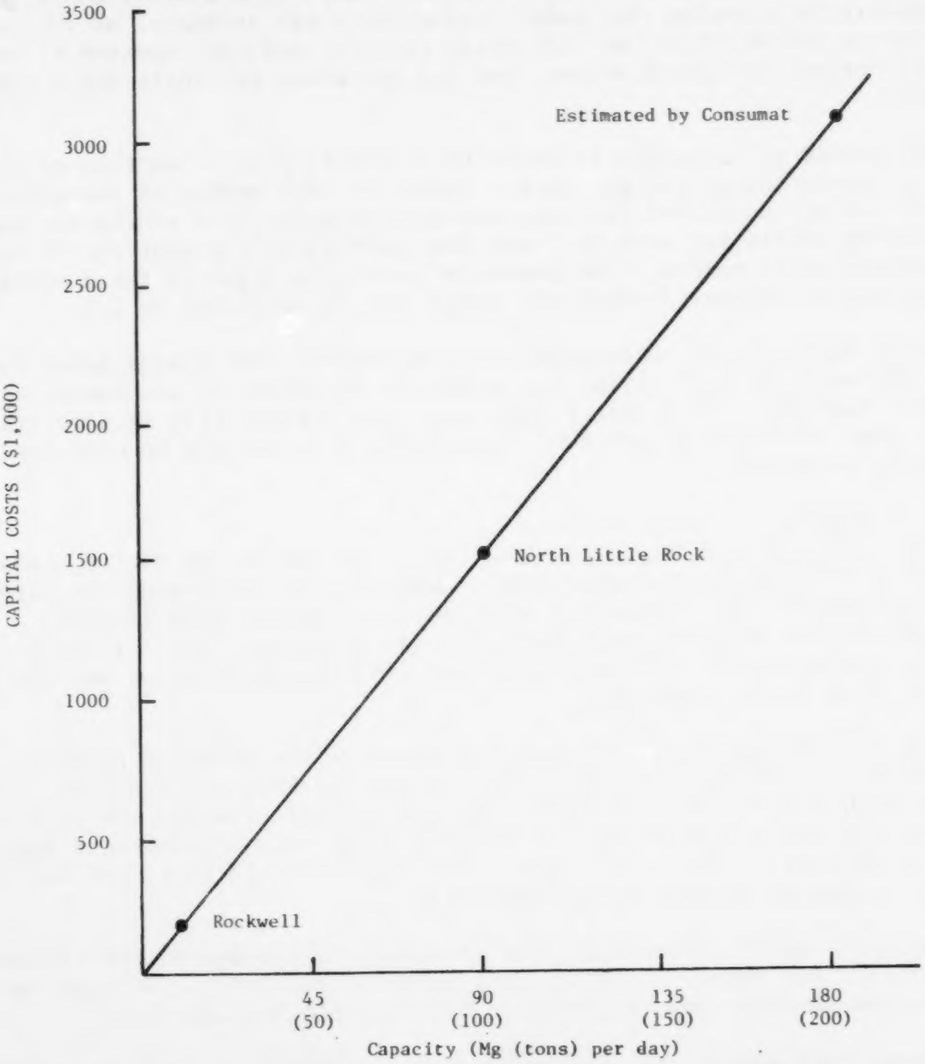


Figure 72. Capital cost of small modular incinerators as a function of rated capacity.

Operation and Maintenance Costs

Labor--

The labor costs for small modular incinerator facilities are a function of many factors including the type of facility (industrial or municipal), hours of operation, and local labor rates. For safety reasons, the minimum number of operators per shift is two for a municipal facility but one for an industrial facility if production workers are nearby. Also, an industrial facility requires minimal supervisory and clerical labor which can be provided by the production area. Also because of the low ash content of commercial refuse, the labor for ash disposal in an industrial facility is minimal compared with that in a municipal facility. Based on a minimal number of incinerators in a system, the labor requirements are estimated as follows: one operator per shift for an industrial facility and one supervisor, one clerical worker, one truck driver, and two operators per shift for a municipal facility.

The number of operators required for a facility is a function of the number of operating shifts per week. Therefore, the number of operators required for an industrial facility may be calculated by dividing the number of operating shifts per week by 5 and then increasing the quotient to the next highest whole number. The number of operators required for a municipal facility may be estimated similarly except for the division by 2.5.

After the employee requirements are determined, the annual labor cost may be estimated by multiplying the number of employees by the annual salary including benefits. While wages will vary considerably from site to site, an average wage of \$10/hr or \$20,800/yr including benefits may be used for estimating purposes.

Auxiliary Fuel--

The amount of auxiliary fuel used is a function of the system chosen and the number of start-ups and shutdowns. Some systems, including the Marysville facility, operate the afterburner after start-up while other systems, including the North Little Rock facility, use auxiliary fuel only during start-up and shutdown. The auxiliary fuel used during start-up and shutdown is a function of the capacity.

The optimum auxiliary fuel usage at North Little Rock per unit of capacity was 3.1 kℓ/MgPD (0.1 MCF/TPD) for one start-up and shutdown. The daily auxiliary fuel usage at Marysville per unit of capacity was 32.1 kℓ/MgPD (1.0 MCF/TPD) for one start-up and shutdown along with intermittent operation of the afterburner. The high usage at the Marysville facility was due to the facility operation at one-half of capacity.

Using the above information, the auxiliary fuel usage may be estimated empirically. The annual auxiliary fuel usage in kiloliters per year for start-up and shutdown may be estimated by the following equation:

$$\text{Annual fuel usage} = \frac{\text{start-ups}}{\text{year}} \times \frac{3.1\ \text{k}\ell/\text{MgPD}}{\text{start-up}} \times \text{capacity (MgPD)}$$

The auxiliary fuel usage for maintaining the afterburner temperature when operating below capacity may be estimated on a proportional basis by the following equation:

$$\text{Annual fuel usage} = [(0.64 \times \%\ \text{of rated capacity}) + 64.2]\ \frac{\ell}{\text{Mg}}$$

$$\times\ \text{capacity}\ \frac{\text{Mg}}{\text{day}}$$

$$\times\ \frac{\text{operating days}}{\text{year}}$$

The sum of the last two equations gives an estimate of the annual auxiliary fuel costs. While fuel oil, natural gas, propane, or other fuel can be used, a reasonable unit cost for natural gas would be \$0.088/kℓ (\$2.50/MCF).

Electric Power--

The electric power usage should be a function of capacity since approximately 85 percent of the electric power is used by the various fans and blowers. Since the blowers also operate during start-up and burndown, there is very little difference in the electric usage between a 2- and a 3-shift operation. The electric power demands per unit capacity for the Marysville and North Little Rock facilities were 0.4 kw/MgPD (0.3 kw/TPD) and 1.0 kw/MgPD (0.9 kw/TPD). The difference in the electric demand per unit capacity between these two facilities was principally due to the Marysville facility operating at 50 percent of capacity and having the hot water heat recovery which has lower pumping costs than the steam heat recovery. On the basis of the above information, the electric usage at a small modular facility may be estimated by the following equation (which is slightly conservative):

$$\text{Annual electric usage} = \frac{\text{operation days}}{\text{year}}$$

$$\times\ \frac{24\ \text{hours}}{\text{day}}\ \times\ \frac{1.0\ \text{kw}}{\text{MgPD}}$$

$$\times\ \text{capacity (MgPD)}$$

The annual electric cost may then be estimated by multiplying the annual electric usage rate by the unit electric costs. A representative value for the unit electric costs is approximately \$0.035/kw-hr.

Water--

The water usage at a small modular incinerator facility is a function of the heat recovery method, the heat recovery rate, the flame quench rate, and the residue quench rate. Since the water cost is a small percentage of the total annual plant costs, a conservative estimate of water usage will be sufficient. The most water-intensive heat recovery method is steam production with no condensate return. Assuming an industrial refuse (16.2 MJ/kg, 7000 Btu/lb), a 60 percent energy recovery, a 10 percent blowdown, and no condensate return, the annual water usage for steam production may be estimated by the following equation:

$$\text{Water usage } \frac{\ell}{\text{year}} = \frac{\text{operating days}}{\text{1 year}} \times \frac{\text{Mg refuse}}{\text{day}} \times \frac{\text{boiler efficiency \%}}{100} \times \frac{\text{1 Kg water}}{\text{2.257 MJ}} \times \frac{\text{1 liter}}{\text{1 Kg water}} \times \frac{\text{MJ heat}}{\text{1 Mg refuse}}$$

Although the annual water usage for flame quenching in the primary chamber should be low, it may be estimated by the following equation which is based on the Marysville data:

$$\text{Water usage } \frac{\ell}{\text{year}} = \frac{\text{operating days}}{\text{year}} \times \frac{200\ell\text{ water}}{\text{Mg refuse}} \times \frac{\text{Mg refuse}}{\text{day}}$$

Assuming a wet-to-wet residue/refuse ratio of 45 percent (worst case for municipal refuse) and a residue moisture content of 30 percent, the annual water usage for residue quenching may be estimated by the following equation:

$$\text{Water usage } \frac{\ell}{\text{year}} = \frac{\text{operating days}}{\text{year}} \times \frac{\text{Mg refuse}}{\text{day}} \times \frac{130\ell\text{ water}}{\text{Mg refuse}}$$

The total annual estimated water usage is the sum of the three water usages. The annual water cost may be estimated by multiplying the total annual usage by the unit costs. A conservative unit water cost based on the Marysville data would be \$0.24/1000ℓ.

Chemicals--

The cost of chemicals is an extremely small portion of the operating cost and is a function of many factors. Therefore, on the basis of the chemical costs at the North Little Rock facility, the chemical costs may be estimated conservatively by the following equation:

$$\text{Cost (\$)} = \frac{\text{Mg waste}}{\text{day}} \times \frac{\text{operating days}}{\text{year}} \times \frac{\$.25}{\text{Mg waste}}$$

Residue Disposal--

The amount of residue requiring disposal is a function of the ash content of the refuse, and the degree of burnout. In some instances, the residue disposal costs will be negligible if the residue can be used as a fill material as at North Little Rock or can be buried on site as at Marysville. Assuming a wet-to-wet residue/refuse ratio, the annual amount of residue requiring disposal may be estimated conservatively by the following equation:

$$\text{Residue } \frac{\text{Mg}}{\text{year}} = \frac{\text{Actual Mg refuse}}{\text{day}} \times \text{Burnout } \frac{\text{Mg residue}}{\text{Mg refuse}} \times \frac{\text{operating days}}{\text{year}}$$

If a landfill is owned by the owner of the incineration facility, the cost of residue disposal would be on a volume basis, but most landfill operators charge on a weight basis. On a weight basis, a reasonable unit cost is $4.00/Mg ($4.44/ton).

Maintenance--

Assuming that the annual maintenance costs are 3.5 percent of the depreciable capital assets, the annual maintenance costs for materials may be estimated by the following equation:

$$\text{Cost (\$)} = \$17{,}500 \times \text{capacity (MgPD)} \times 0.035$$

The 3.5 percent value was used rather than the 5.5 percent, which is an IRS guideline for a solid waste processing plant, because of the small number of moving parts. Also, it may be assumed that the operators will have sufficient time to do some maintenance work.

Depreciation and Interest--

For a given capital cost and interest rate and an estimated useful life, the depreciation and interest may be calculated by the amortization (capital recovery) method. Most industrial facilities would probably use an estimated life of 3 to 8 years and an interest rate of 10 to 15 percent. For most municipal facilities, an estimated useful life of 10 to 20 years and an interest rate of 6 to 10 percent would be used. For a given estimated life in years (n) and a given interest rate expressed as a decimal (i), the annual depreciation and interest cost may be estimated by the following formula:

$$\text{Cost (\$)} = \$17{,}500 \times \text{capacity (MgPD)} \times \left(\frac{i\,(1+i)^n}{(1+i)^n - 1} \right)$$

Revenues

The revenues from energy recovery are a function of the heat content of the refuse, the thermal efficiency of the system, and the recovered value of the energy. Typical refuse heat content values are 10.4 and 17.4 MJ/kg (4500 and 7500 Btu/lb) for municipal and industrial refuse, respectively. The efficiencies of the systems are approximately 60 percent for a 3-shift operation but only 35 percent for a 2-shift operation because of burndown losses. While the efficiencies for different capacities and systems vary, the variations are minimal. Assuming that none of the flue gases bypass the boiler, the energy recovery rate for the 2- and 3-shift operations may be estimated by the following equation:

$$\text{Recovered energy}\left(\frac{\text{MJ}}{\text{year}}\right) = \text{capacity (MgPD)} \times \%\text{ of rated capacity}$$
$$\times\ S \times \text{refuse heat content} \times \frac{\text{operation days}}{\text{year}}$$

where $S = 350$ for the two shifts and 600 for the three shifts

When the recovered energy is used to replace other fuels, the savings may be calculated by using the costs for the other fuels.

Fuel	Value ($/MJ)	Value ($/MBtu)
Fuel oil	$0.00311	$3.28
Electric	0.00769	8.11
Natural gas	0.00245	2.59
Propane	0.00404	4.25
Steam	0.00427	4.50

However, if the energy is sold, it is usually sold at a discounted price. The cost of steam production is usually assumed to be $11.00/1000 kg ($5.00/1000 lb), but the steam produced at North Little Rock was sold for $5.72/1000 kg ($2.60/1000 lb).

Net Cost of Operation

The net cost of operation is the difference between the operating and maintenance costs and the revenues.

Effect of Operation Variables

Of the variables that affect net operation cost, the capacity of the unit, the percentage of capacity at which the system is operated, and the percentage of operating time are the variables that can most likely be controlled. To determine the effects of these variables on net operating costs, the net operating costs were estimated by applying the previously developed equations to the following six modes of operation.

A: 2 shifts per day, 5 days per week, 50% of rated capacity
B: 2 shifts per day, 5 days per week, 100% of rated capacity
C: 3 shifts per day, 5 days per week, 50% of rated capacity
D: 3 shifts per day, 5 days per week, 100% of rated capacity
E: 3 shifts per day, 7 days per week, 50% of rated capacity
F: 3 shifts per day, 7 days per week, 100% of rated capacity

Municipal Facilities--

To determine the net operating costs of the municipal facilities, the following assumptions were made: (1) the average employee salary is \$20,800 per year including benefits, (2) the auxiliary fuel used is natural gas at a unit cost of \$0.088/kℓ (\$2.50 MCF), (3) the electric power unit cost is \$0.035/kwhr, (4) the unit cost of water is \$0.24/kℓ (\$0.91/1000 gal), (5) the wet-to-wet residue/refuse ratio is 0.40, (6) the cost of residue disposal is \$4/Mg, (7) the interest rate is 7 percent, (8) the estimated life of the facility is 15 years, (9) the heat content of the refuse is 10.4 MJ/kg (4500 Btu/lb), and (10) the recovered energy value is \$0.00245/MJ (\$2.60/MBtu). The net annual operating costs for the six operating modes are shown in Figure 73 and the net costs per megagram (ton) of refuse processed are shown in Figure 74.

Both of these curves illustrate the benefit of operating the units at capacity to reduce operating costs. Therefore, before a facility is designed, the amount of refuse to be processed should be accurately determined before the capacity of the facility is chosen. The estimated net operating costs shown in Figure 74 indicate that the chosen operation modes are not optimum when the capacities are less than 45 MgPD. Figure 74 also indicates that as the percentage of operating time increases, the net operating cost decreases.

At the higher capacities, Mode F becomes less expensive, but the small difference is probably not worth the additional effort for the 7-day week operation. Although the curves in Figures 73 and 74 will not likely match an actual operation because they are based on several assumptions, they are sufficiently representative to indicate trends and average costs.

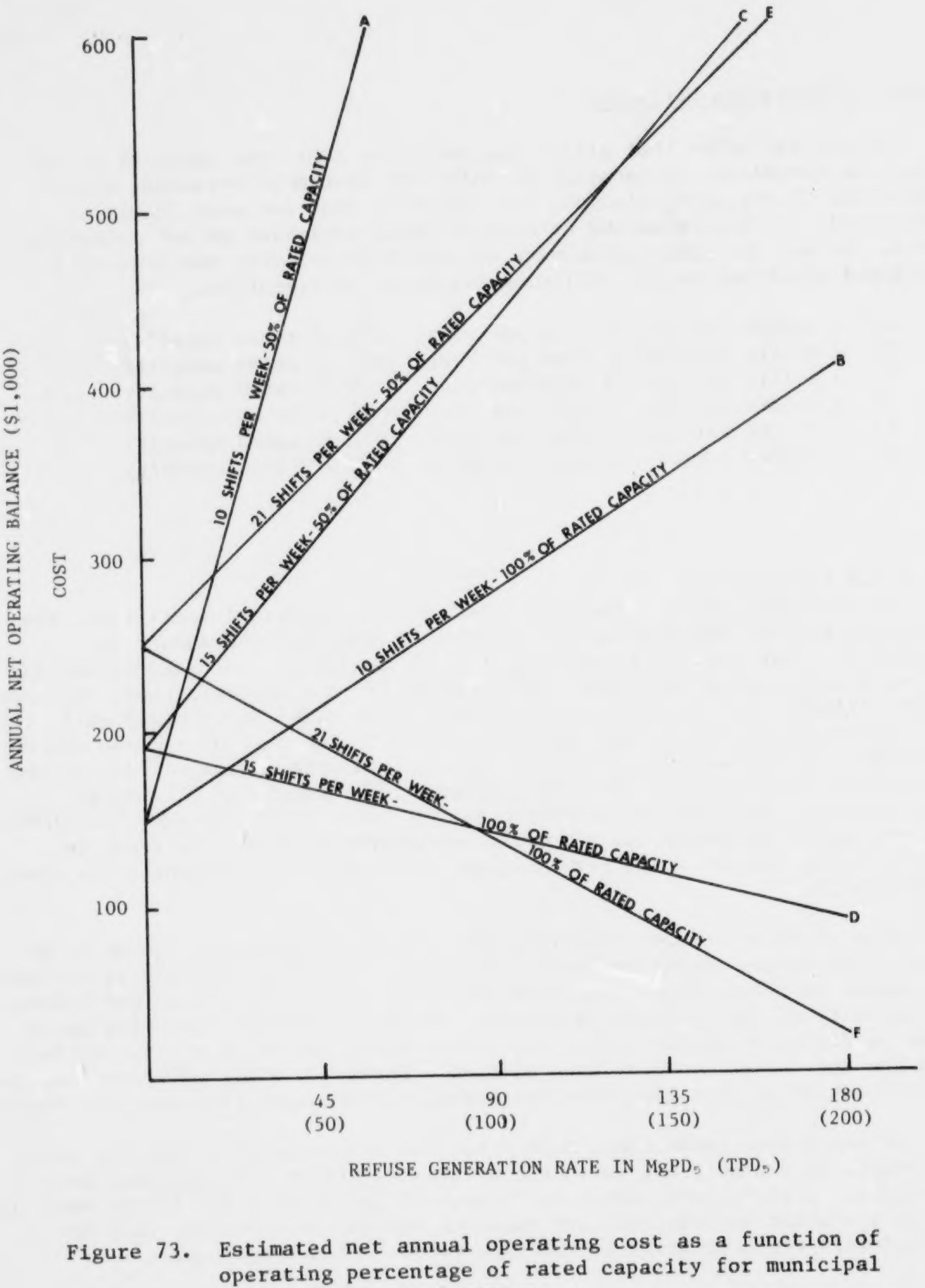


Figure 73. Estimated net annual operating cost as a function of operating percentage of rated capacity for municipal small modular incinerators.

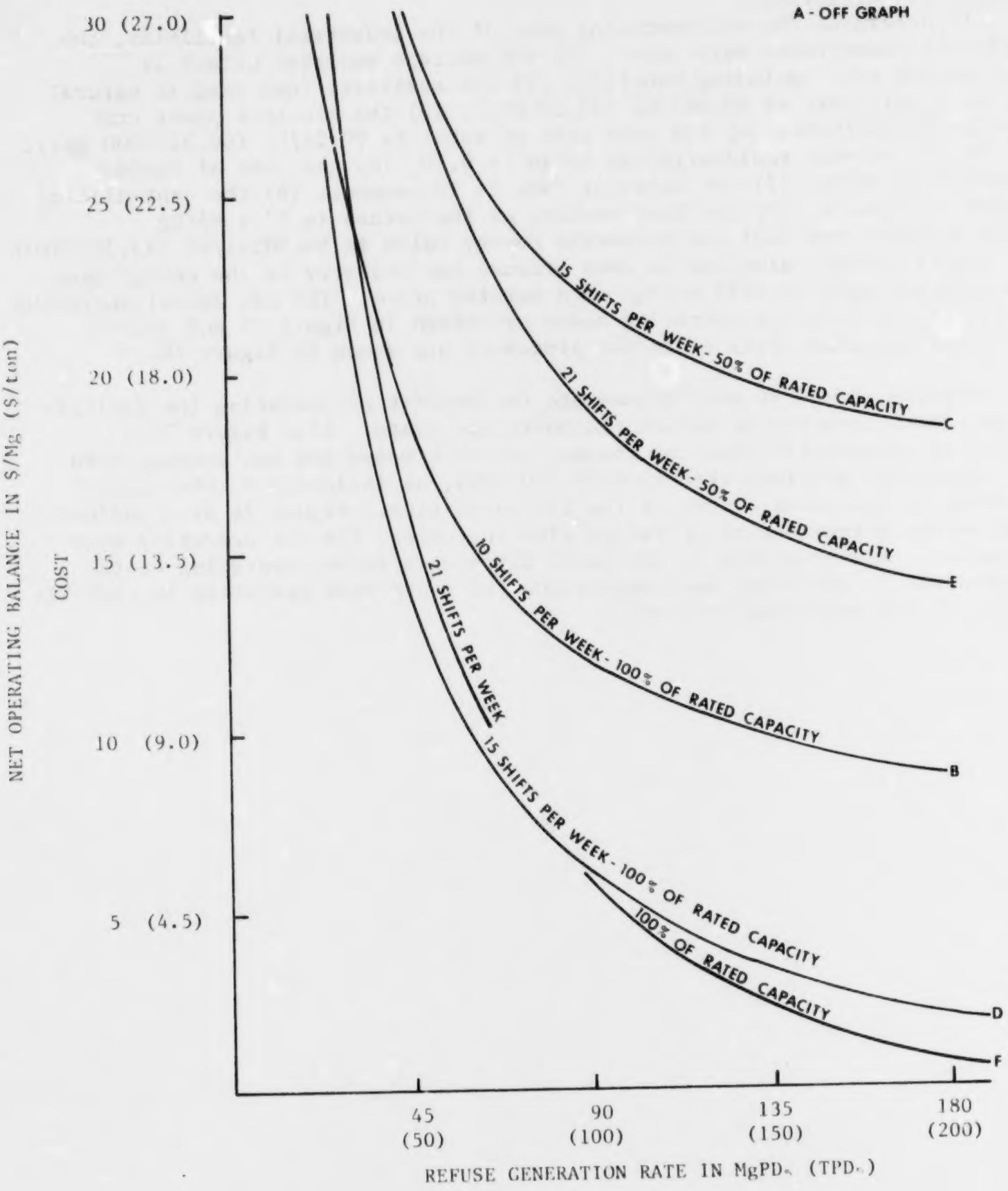


Figure 74. Estimated net annual operating cost as a function of refuse feed rate, shifts per week, and operating percentage of rated capacity for municipal small modular incinerators.

Industrial Facilities--

To determine the net operating cost of the industrial facilities, the following assumptions were made: (1) the average employee salary is $20,800 per year including benefits, (2) the auxiliary fuel used is natural gas at a unit cost of $0.088/kℓ ($2.50 MCF), (3) the electric power unit cost is $0.035/kwhr, (4) the unit cost of water is $0.24/kℓ ($0.91/1000 gal), (5) the wet-to-wet residue/refuse ratio is 0.10, (6) the cost of residue disposal is $4/Mg, (7) the interest rate is 12 percent, (8) the depreciation period is 7 years, (9) the heat content of the refuse is 17.4 MJ/kg (7500 Btu/lb), and (10) the recovered energy value is $0.00311/MJ ($3.28/MBtu). The higher energy value can be used because the industry is the energy user and does not have to sell energy at a derated price. The net annual operating costs for the same six operating modes are shown in Figure 75 and the net costs per megagram (ton) of refuse processed are shown in Figure 76.

Figures 75 and 76 also illustrate the benefit of operating the facility at the rated capacity to reduce the operation costs. Like Figure 74, Figure 76 illustrates that the chosen operation modes are not optimum when the capacities are less than 45 MgPD (50 TPD), as indicated by the rapid increase in the curve slopes at the low capacities. Figure 76 also indicates that as the percentage of operating time increases, the net operating cost decreases. Again because of the small difference in net operating costs between the 5- and 7-day week operation. the 7-day week operation is probably not worth the additional effort.

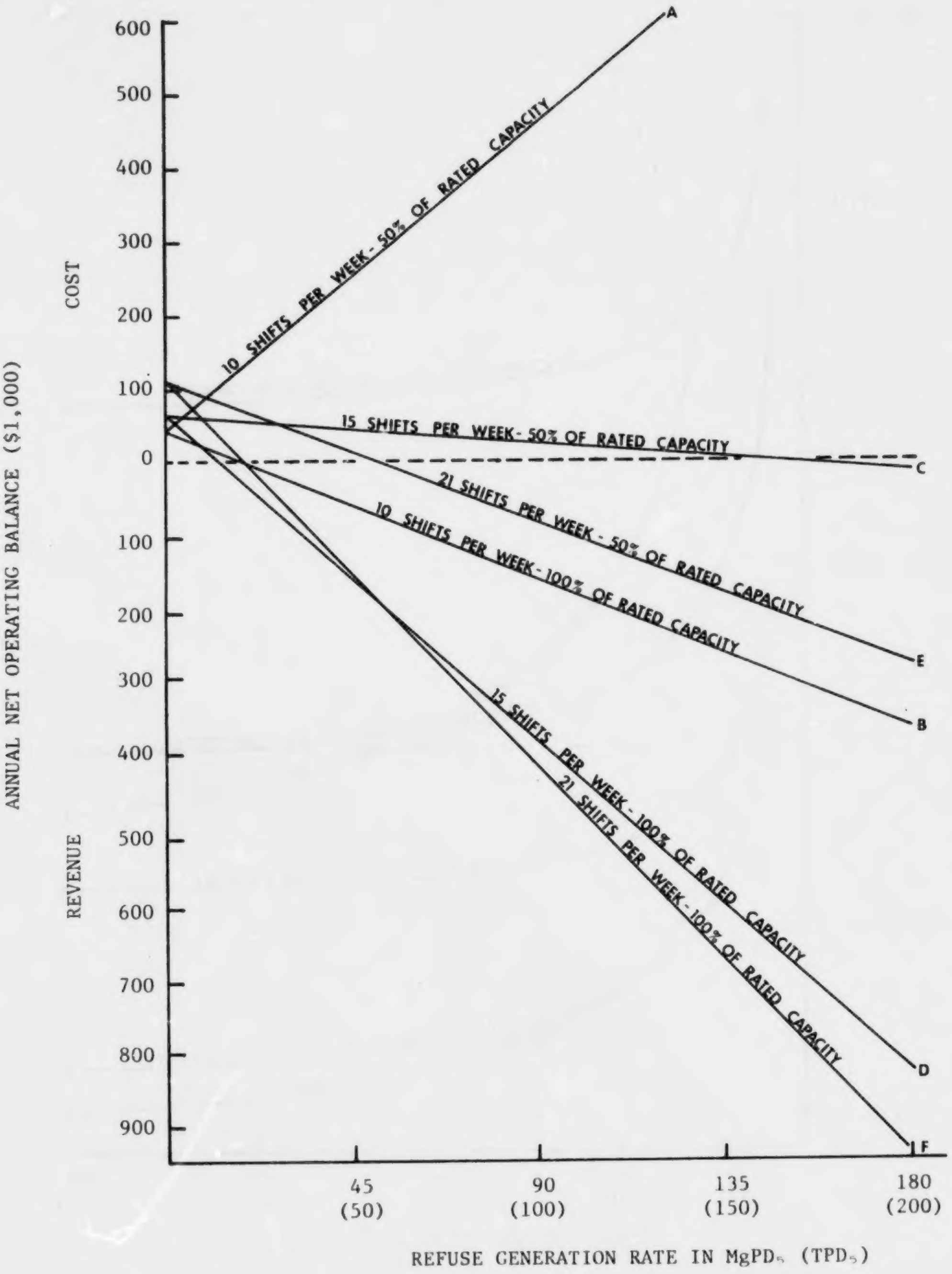


Figure 75. Estimated net annual operating cost as a function of operating percentage of rated capacity for industrial small modular incinerators.

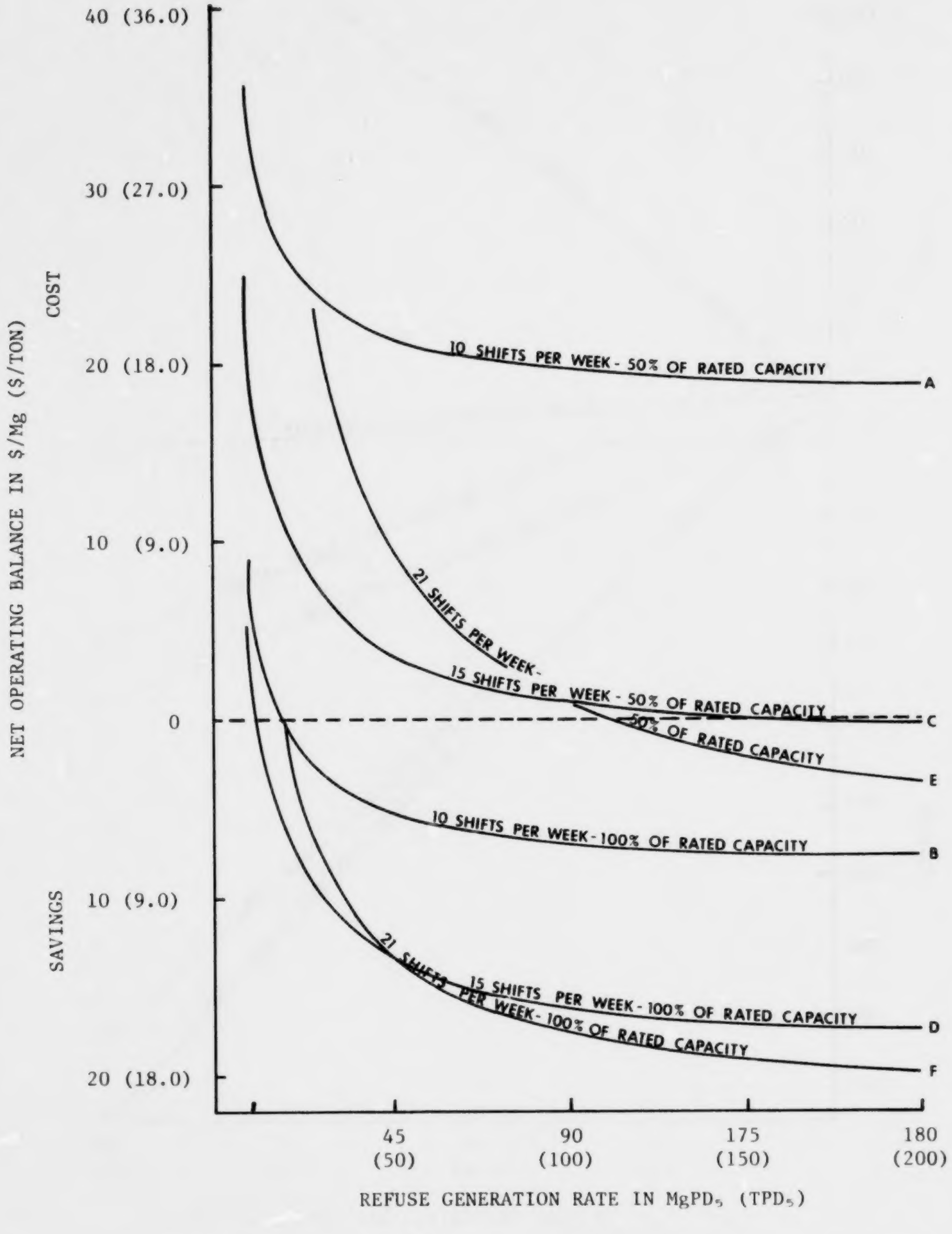


Figure 76. Estimated net annual operating cost as a function of refuse feed rate, shifts per week, and operating percentage of rated capacity for industrial small modular incinerators.

APPENDIX A

DETAILED TEST RESULTS

TABLE A-1. LIST OF EQUIPMENT MODIFICATIONS IN NORTH LITTLE ROCK FACILITY BEFORE OCTOBER 1978 TEST

Modifications reported by Consumat Systems, Inc.

1.	Conveyor drive:	The original mechanical drive was converted to a hydraulic drive to make the conveyor operation more reliable.
2.	Ash chute:	A retractable extension was incorporated in the chute to reduce secondary pollution.
3.	Ash removal system:	A quench water spray was installed in the ash discharge shroud to prevent build-up of excess pressure. The subsequent spray effect minimized blow-back into the incinerator.
4.	Ash removal ram:	The cycle time was increased to make the retention time in the primary chamber longer. The longer retention time improved the ash quality.
5.	Cooling system:	A cooling system for the primary chamber was added to control the temperature of the ash removal sump, ash transfer rams, and underfire air tubes. The consequent benefits were a positive primary chamber ash pile temperature, reduced slagging, and a heat source that was utilized for feedwater heating.
6.	Orifices:	The air control to the orifices was improved to better the airflow to the primary chamber.
7.	Underfire air ports:	The ports were redesigned to introduce underfire air more reliably and without port plugging.
8.	Draft control:	A draft control was installed to make the draft throughout the entire system more uniform and efficient.

(continued)

TABLE A-1 (continued)

Modifications observed by SYSTECH

1.	Residue transfer rams:	The air tubes in each ram were increased from two to four.
2.	Temperature control:	The operational temperature of the primary chamber was lowered to 1200° F; the water sprays in the primary chamber were removed, and a refuse load indicator panel was added to the central control system.
3.	Soot blower system:	The air pressure was increased; more tubes were added to the soot blower assembly; and the airflow control system was improved.
4.	Flue gas flow controls:	The damper valve in the boiler exhaust stack was removed, and the dump stack cap was replaced with one of an improved design.
5.	Residue removal system:	A pipe extending from the residue water pit to the primary chamber was installed so that gas would bypass the residue bed and thereby prevent residue blow-back.

TABLE A-2. NORTH LITTLE ROCK REFUSE COMPOSITION BY HAND SORT SAMPLES

Test Period	Sample Size(lb)	% of total refuse received	Food	Garden	Paper	Plastic	Textiles	Wood	Ferrous	Aluminum	Glass	Inerts	Fines	Total (lb)
March	1137	0.3												
3/20			9.4	14.5	66.6	8.0	0.0	0.0	12.5	2.5	19.0	2.0	6.5	141
3/21			5.5	5.0	61.5	5.5	4.6	0.5	5.5	1.5	9.0	6.5	0.5	105
3/22			45.3	37.0	162.7	25.1	19.8	8.0	25.1	3.8	35.8	6.9	11.0	381
3/23			39.8	25.0	255.5	30.6	14.8	7.7	51.0	4.1	60.7	2.6	17.9	510
May	1676	0.5												
5/22			27.1	2.3	139.2	21.7	4.3	0.8	42.8	0.0	51.2	0.0	18.6	308
5/23			33.0	6.4	184.1	35.8	5.2	5.2	35.0	10.5	57.5	1.6	27.7	402
5/24			23.4	29.8	238.7	32.6	11.0	4.6	39.0	11.5	51.4	4.1	12.9	459
5/25			29.4	30.9	268.7	34.8	4.6	7.6	47.7	8.6	37.5	1.5	36.5	507
October	2907	0.7												
10/6			12.1	0.8	107.5	13.3	0.4	1.2	16.3	0.7	21.9	1.3	18.3	193.8
10/9			75.5	30.4	289.8	54.1	12.9	4.5	62.0	17.1	43.9	0.9	22.0	613.1
10/10			51.9	31.7	397.5	57.6	28.2	5.6	74.5	14.9	28.9	4.9	53.0	748.2
10/11			47.7	23.6	414.7	65.0	13.9	4.0	55.6	18.8	75.6	0.0	17.6	736.5
10/12			10.8	1.8	357.7	67.7	8.1	14.5	45.9	47.8	50.6	0.9	8.1	613.9

TABLE A-3. NORTH LITTLE ROCK DAILY REFUSE COMPOSITION FOR MARCH

Category	Daily percentage					Total weekly wt	
	3/20	3/21	3/22	3/23	Avg.	(kg)	(lb)
Food	6.6	5.2	11.9	7.8	7.9	11,764	25,936
Garden	10.3	4.8	9.7	4.9	7.4	11,020	24,294
Paper	47.2	58.6	42.7	50.0	49.6	73,863	162,839
Plastics	5.6	5.2	6.6	6.0	5.9	8,786	19,370
Textiles	0	3.8	5.2	2.9	3.6	5,361	11,819
Wood	0	.5	2.1	1.5	1.2	1,787	3,940
Ferrous	8.8	5.2	6.6	10.0	7.7	11,466	25,279
Aluminum	1.8	1.4	.9	.8	1.2	1,786	3,940
Glass	13.5	8.6	9.4	11.9	10.9	16,232	35,785
Inert	1.4	6.2	1.8	.5	2.5	3,723	8,208
Fines	4.6	.5	2.8	3.5	2.9	4,319	9,521
						150,107	328,304

TABLE A-4. NORTH LITTLE ROCK DAILY REFUSE COMPOSITION FOR MAY

	Daily percentage					Total weekly wt	
Category	5/20	5/23	5/24	5/25	Avg.	(kg)	(lb)
Food	8.3	8.2	5.1	5.8	6.9	10,640	23,458
Garden	0.8	1.6	6.5	6.1	3.7	5,744	12,664
Paper	45.2	45.8	52.0	53.0	48.9	75,556	166,572
Plastics	7.0	8.9	7.1	6.7	7.4	11,465	25,277
Textiles	1.4	1.3	2.4	0.9	1.5	2,313	5,099
Wood	0.3	1.3	1.0	1.5	1.0	1,542	3,399
Ferrous	13.9	8.7	8.5	9.4	10.1	15,575	34,337
Aluminum	0	2.6	2.5	1.7	1.7	2,622	5,780
Glass	16.6	14.3	11.2	7.4	12.4	19,103	42,115
Inert	0	0.4	0.9	0.3	0.4	617	1,360
Fines	6.0	6.9	2.8	7.2	5.7	8,790	19,379
						153,967	339,440

TABLE A-5. COMPOSITION AND ANALYSIS OF AN AVERAGE MUNICIPAL REFUSE FROM STUDIES MADE BY PURDUE UNIVERSITY*

Component	Percent of All Refuse by Weight	Moisture (percent by weight)	Analysis (percent dry weight)							Calorific Value (Btu/lb)
			Volatile Matter	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Noncombustibles[b]	
					Rubbish, 64%					
Paper	42.0	10.2	84.6	43.4	5.8	44.3	0.3	0.20	6.0	7572
Wood	2.4	20.0	84.9	50.5	6.0	42.4	0.2	0.05	1.0	8613
Grass	4.0	65.0	—	43.3	6.0	41.7	2.2	0.05	6.8	7693
Brush	1.5	40.0	—	42.5	5.9	41.2	2.0	0.05	8.3	7900
Greens	1.5	62.0	70.3	40.3	5.6	39.0	2.0	0.05	13.0	7077
Leaves	5.0	50.0	—	40.5	6.0	45.1	0.2	0.05	8.2	7096
Leather	0.3	10.0	76.2	60.0	8.0	11.5	10.0	0.40	10.1	8850
Rubber	0.6	1.2	85.0	77.7	10.4	—	—	2.0	10.0	11330
Plastics	0.7	2.0	—	60.0	7.2	22.6	—	—	10.2	14368
Oils, paints	0.8	0.0	—	66.9	9.7	5.2	2.0	—	16.3	13400
Linoleum	0.1	2.1	65.8	48.1	5.3	18.7	0.1	0.40	27.4	8310
Rags	0.6	10.0	93.6	55.0	6.6	31.2	4.6	0.13	2.5	7652
Street sweepings	3.0	20.0	67.4	34.7	4.8	35.2	0.1	0.20	25.0	6000
Dirt	1.0	3.2	21.2	20.6	2.6	4.0	0.5	0.01	72.3	3790
Unclassified	0.5	4.0	—	16.6	2.5	18.4	0.05	0.05	62.5	3000
					Food Wastes, 12%					
Garbage	10.0	72.0	53.3	45.0	6.4	28.8	3.3	0.52	16.0	8484
Fats	2.0	0.0	—	76.7	12.1	11.2	0	0	0	16700
					Noncombustibles, 24%					
Metals	8.0	3.0	0.5	0.8	0.04	0.2	—	—	99.0	124
Glass and ceramics	6.0	2.0	0.4	0.6	0.03	0.1	—	—	99.3	65
Ashes	10.0	10.0	3.0	28.0	0.5	0.8	—	0.5	70.2	4172
					Composite Refuse, as Received					
All refuse	100	20.7	—	28.0	3.5	22.4	0.33	0.16	24.9	6203

[a] Data from [1].

[b] Ash, metal, glass, and ceramics.

TABLE A-6. NORTH LITTLE ROCK REFUSE MOISTURE CONTENT OF DAILY HAND SORTS

	Moisture content(%)								
	Date								
Category	3/20	3/23	3/24	5/22	5/24	10/9	10/10	10/11	10/12
Food	52.3	*	60.9	49.4	59.4	68.4	61.4	65.4	60.0
Garden	*	*	36.4	26.3	60.6	*	57.3	59.6	35.9
Paper	9.3	10.1	15.8	24.9	35.8	23.8	23.5	13.3	17.3
Plastic	*	*	*	15.2	16.9	12.9	12.4	6.4	23.0
Textiles	*	*	*	9.0	11.0	5.2	36.1	15.3	14.5
Wood	*	*	*	10.9	17.8	13.2	14.3	10.9	10.3
Ferrous	*	*	*	4.8	6.9	9.7	6.7	4.5	7.0
Aluminum	*	*	*	*	3.8	12.2	1.2	19.2	14.6
Glass	*	*	*	1.1	1.5	1.7	4.3	0.5	9.4
Inert	*	*	*	*	*	*	1.0	*	*
Fines	*	*	*	20.4	26.9	41.4	25.8	51.9	19.7

* No test sample

TABLE A-7. NORTH LITTLE ROCK PARTICULATE EMISSION DATA

Date	Particulate		Isokinetic	CO_2	Particulate*	
	(g/scm)	(gr/scf)	%	(%)	(g/scm)	(gr/scf)
03/21	0.0986	0.0431	111.0	2.8	0.4227	0.1847
03/21	0.0817	0.0357	106.8	2.8	0.3501	0.1530
03/22	0.1000	0.0437	118.8	3.5	0.3428	0.1498
03/22	0.0666	0.0291	114.4	3.5	0.2284	0.0998
03/23	0.0641	0.0281	126.0	2.8	0.2747	0.1205
05/22	0.0984	0.0430	129.0	2.8	0.4217	0.1843
05/22	0.1030	0.0450	139.0	2.7	0.4577	0.2000
05/23	0.0892	0.0390	136.0	2.5	0.4284	0.1872
05/23	0.0824	0.0360	134.0	2.5	0.3954	0.1728
05/24	0.1007	0.0440	134.0	1.9	0.6359	0.2779
05/24	0.0915	0.0400	129.0	1.9	0.5780	0.2526
05/25	0.0870	0.0380	109.0	2.2	0.4744	0.2073
05/25	0.0664	0.0290	137.0	2.2	0.3620	0.1582
05/26	0.0524	0.023	136.0	4.4	0.1416	0.0621
10/09	0.0876	0.0383	95.5	3.8	0.2767	0.1209
10/10	0.1632	0.0713	100.3	3.7	0.5291	0.2312
10/11	0.1213	0.0530	99.7	3.9	0.3732	0.1631
10/11	0.0867	0.0379	101.3	4.7	0.2215	0.0968
10/11	0.0446	0.0195	101.7	3.5	0.1531	0.0669
10/12	0.0760	0.0332	103.5	4.2	0.2172	0.0949
10/12	0.0924	0.0404	99.8	4.4	0.2522	0.1102
10/12	0.0870	0.0380	97.6	4.4	0.2371	0.1036
10/13	0.1183	0.0517	107.4	4.3	0.3302	0.1443
10/13	0.1291	0.0564	98.4	4.1	0.3778	0.1650
Average	0.0918	0.0401		3.3	0.3554	0.1553
Standard Deviation	σ = 0.0105				σ = 0.0549	

*Corrected to 12% CO_2

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TABLE A-8. PARTICULATE EMISSIONS SUMMARY DATA

JOB: North Little Rock, Arkansas - March 1978

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
GENERAL						
Date	3/21	3/21	3/22	3/22	3/23	3/23
Emission Source West side Boiler Stack						
Barometric Pressure (ins. Hg)	29.8	29.8	29.8	29.82	29.69	29.65
Specific Gravity of Gases Referred to Air	28.3750	28.4261	28.4074	28.5268	28.596	28.4072
Coal Usage Rate During Test (lbs./hr.)						
Coal Heat Value (BTU/lb.)						
BTU Input (BTU/hr.)						
Average Steam Load (lbs./hr.)						
GAS FLOW DATA						
Stack Area (ft^2)	10.56					
Avg. Velocity at Stack Conditions (FPM)	2,231.	2,477.	1,859.	1,815.	1,745.	1,850.
Flow Rate at Stack Conditions (CFM)	23,559.	26,165.	19,638.	19,176.	18,435.	19,536.
Stack Temperature (°F)	259.	255.	244.	255.	233.	245.
Flow Rate at Standard Conditions (SCFM)	17,290.	19,312.	14,725.	14,167.	13,974.	14,554.
PARTICULATE EMISSION DATA						
Total Particulate Collected (mg)	161.8	144	149.5	93.4	99.10	106.4
Volume Dry Gas Sampled at Std. Cond. (SCF)	57.79	62.43	52.66	49.38	54.26	54.99
Volume Water Vapor Sampled at Std. Cond. (SCF)	4.15	4.15	3.78	2.95	2.86	3.64
Total Sampled Volume at Std. Cond. (SCF)	61.94	66.53	56.45	52.32	56.83	58.63
Particulate Concentration (gr./SCF)	0.0431	0.0357	0.0437	0.0291	0.0281	0.0298
Particulate Concentration (lbs./SCF) $\times 10^{-6}$	6.16×10^{-6}	5.09×10^{-6}	6.24×10^{-6}	9.16×10^{-6}	4.02×10^{-6}	4.25×10^{-6}
Particulate Emission Rate (lbs./hr.)	5.9	5.5	5.1	3.3	3.2	3.5
Particulate Emission Rate (lbs./10^6 BTU)						
Percent Isokinetic Sample (%)	111.0	106.8	118.6	114.4	126.0	124.3
MISCELLANEOUS DATA						
Grains/SCF Corrected to 12 percent CO_2	0.1848	0.1529	0.1499	0.0999	0.1205	0.1276

(continued)

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TABLE A-8 (continued)

JOB: Little Rock Incinerator Unit - May 1978

GENERAL						
Date	5/22	5/22	5/23	5/23	5/24	5/24
Emission Source	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Barometric Pressure (ins. Hg)	29.75	29.75	29.77	29.77	29.77	29.77
Specific Gravity of Gases Referred to Air	28.19	27.99	28.22	28.00	27.92	28.15
Coal Usage Rate During Test (lbs./hr.)						
Coal Heat Value (BTU/lb.)						
BTU Input (BTU/hr.)						
Average Steam Load (lbs./hr.)						
GAS FLOW DATA						
Stack Area (ft^2)	10.56					
Avg.Velocity at Stack Conditions (FPM)	2,197	2,412	2,258	1,970	2,269	2,334
Flow Rate at Stack Conditions (CFM)	23,201	25,479	23,850	20,812	23,962	24,652
Stack Temperature (°F)	260.	249.	252.	255.	243.	239.
Flow Rate at Standard Conditions (DSCFM)	15,536	17,559	16,309	13,865	16,504	17,154
PARTICULATE EMISSION DATA						
Total Particulate Collected (mg)	182.0	231.7	181.2	138.8	205.1	185.1
Volume Dry Gas Sampled at Std. Cond. (SCF)	64.8	78.9	71.9	60.2	71.8	71.3
Volume Water Vapor Sampled at Std. Cond. (SCF)	6.0	6.2	6.0	6.4	6.4	6.0
Total Sampled Volume at Std. Cond. (SCF)	8.5	7.3	7.7	9.7	8.2	7.7
Particulate Concentration (gr./SCF)	.043	.045	.039	.036	.044	.040
Particulate Concentration (lbs./SCF) × 10^{-6}	6.2	6.5	5.5	5.1	6.3	5.7
Particulate Emission Rate (lbs./hr.)	5.8	6.8	5.4	6.1	6.2	5.9
Particulate Emission Rate (lbs./10^6 BTU)	.32		.36		.49	
Percent Isokinetic Sample (%)	129.	139.	136.	134.	134.	129.
MISCELLANEOUS DATA						
Grains/SCF Corrected to 12 percent CO_2	0.1855	0.2010	0.1862	0.1704	0.2778	0.2523

(continued)

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TABLE A-8 (continued)

JOB: Little Rock Incinerator Unit - May 1978

GENERAL						
Date	5/25	5/25	5/26	5/26		Average
Emission Source	Run 7	Run 8	Run 9	Run 10		
Barometric Pressure (ins. Hg)	29.77	29.77	29.70	29.70		29.76
Specific Gravity of Gases Referred to Air	28.12	28.19	28.99	29.05		28.28
Coal Usage Rate During Test (lbs./hr.)						
Coal Heat Value (BTU/lb.)						
BTU Input (BTU/hr.)						
Average Steam Load (lbs./hr.)						
GAS FLOW DATA						
Stack Area (ft^2)	10.56					10.56
Avg. Velocity at Stack Conditions (FPM)	1,939	1,658	2,470	1,498		2,167
Flow Rate at Stack Conditions (CFM)	20,479	17,517	26,084	15,820		22,893
Stack Temperature (°F)	230	234.	217.	226.		242
Flow Rate at Standard Conditions (SCFM)	14,321	12,259	18,883	11,368		15,821
PARTICULATE EMISSION DATA						
Total Particulate Collected (mg)	125.8	103.0	149.1	75.7		166.9
Volume Dry Gas Sampled at Std. Cond. (SCF)	50.7	54.6	83.1	50.1		67.5
Volume Water Vapor Sampled at Std. Cond. (SCF)	4.7	4.3	6.1	3.4		5.8
Total Sampled Volume at Std. Cond. (SCF)	8.5	7.3	6.8	6.3		8.0
Particulate Concentration (gr./SCF)	.038	.029	.028	.023		.038
Particulate Concentration (lbs./SCF)	5.5	4.2	3.9	3.3		5.4
Particulate Emission Rate (lbs./hr.)	4.7	3.1	4.5	2.3		5.4
Particulate Emission Rate (lbs./10^6 BTU)	.44					.40
Percent Isokinetic Sample (%)	109.	137.	136.	136.		---
MISCELLANEOUS DATA						
Grains/SCF Corrected to 12 percent CO_2	0.2083	0.1594	0.0736	0.0621		

(continued)

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TABLE A-8 (continued)

JOB: North Little Rock, Arkansas, October 1978

GENERAL						
Date	10/09	10/10	10/11	10/11	10/11	10/12
Emission Source						
Barometric Pressure (ins. Hg)	29.95	29.92	29.90	29.90	29.90	29.90
Specific Gravity of Gases Referred to Air	28.791	28.412	28.587	28.663	28.74	28.536
Coal Usage Rate During Test (lbs./hr.)						
Coal Heat Value (BTU/lb.)						
BTU Input (BTU/hr.)						
Average Steam Load (lbs./hr.)						
GAS FLOW DATA						
Stack Area (ft^2)	10.56					
Avg. Velocity at Stack Conditions (FPM)	2,213.	2,108.	2,069.	2,107.	2,034.	2,108.
Flow Rate at Stack Conditions (CFM)	23,369.	22,268.	21,854.	22,252.	21,483.	22,263.
Stack Temperature (°F)	277	286	286	289	289	287
Flow Rate at Standard Conditions (SCFM)	16,822.	15,820.	15,516.	15,735.	15,192.	15,785.
PARTICULATE EMISSION DATA						
Total Particulate Collected (mg)	148.2	263.2	193.7	142.3	72.2	126.9
Volume Dry Gas Sampled at Std. Cond. (SCF)	59.59	56.85	56.25	57.82	57.08	58.95
Volume Water Vapor Sampled at Std. Cond. (SCF)	2.61	4.6	3.697	3.91	2.75	4.36
Total Sampled Volume at Std. Cond. (SCF)	62.2	61.45	59.95	61.73	59.83	63.31
Particulate Concentration (gr./SCF)	0.0383	0.0713	0.0530	0.0380	0.0195	0.0332
Particulate Concentration (lbs./SCF)	5.47×10^{-6}	1.02×10^{-5}	7.57×10^{-6}	5.41×10^{-6}	2.78×10^{-6}	4.73×10^{-6}
Particulate Emission Rate (lbs./hr.)	5.29	8.94	6.62	4.79	2.42	4.17
Particulate Emission Rate (lbs./10^6 BTU)						
Percent Isokinetic Sample (%)	95.4	100.2	99.7	101.2	101.6	103.5
MISCELLANEOUS DATA						
Run No. 1 was run on 10/6/78 only as as preliminary run.						
Grains/SCF Corrected to 12 percent CO_2	.121	.231	.163	.097	.067	.095

(continued)

TABLE A-8 (continued)

JOB: North Little Rock, Arkansas, October 1978

GENERAL						
Date	10/12	10/12	10/13	10/13		
Emission Source						
Barometric Pressure (ins. Hg)	29.90	29.52	29.80	29.50		
Specific Gravity of Gases Referred to ir	28.584	28.71	28.59	28.55		
Coal Usage Rate During Test (lbs./hr.)						
Coal Heat Value (BTU/lb.)						
BTU Input (BTU/hr.)						
Average Steam Load (lbs./hr.)						
GAS FLOW DATA						
Stack Area (ft^2)	10.56					
Avg. Velocity at Stack Conditions (FPM)	2,138.	2,081.	2,270.	2,481.		
Flow Rate at Stack Conditions (CFM)	22,582.	21,983.	23,972.	26,206.		
Stack Temperature (°F)	289	288	285	274		
Flow Rate at Standard Conditions (SCFM)	15,969.	15,368.	16,985.	18,657.		
PARTICULATE EMISSION DATA						
Total Particulate Collected (mg)	151.1	135.2	221.5	243.3		
Volume Dry Gas Sampled at Std. Cond. (SCF)	57.55	54.84	66.02	66.4		
Volume Water Vapor Sampled at Std. Cond. (SCF)	4.15	3.27	4.69	4.72		
Total Sampled Volume at Std. Cond. (SCF)	61.7	58.11	70.71	[illegible].12		
Particulate Concentration (gr./SCF)	0.0404	0.0380	0.0517	0.0564		
Particulate Concentration (lbs./SCF)	5.77×10^{-6}	5.42×10^{-6}	7.38×10^{-6}	8.06×10^{-6}		
Particulate Emission Rate (lbs./hr.)	5.16	4.72	7.02	8.42		
Particulate Emission Rate (lbs./10^6 BTU)						
Percent Isokinetic Sample (%)	99.7	97.6	107.4	98.4		
MISCELLANEOUS DATA						
Grains/SCF Corrected to 12 percent CO_2	.110	.103	.144	.165		

TABLE A-9. NORTH LITTLE ROCK STACK OPACITY DURING OCTOBER TEST

Date	Opacity * (%)									Avg(%)
10/6	31	41	35	45	57	45				42
10/9	28	32	36	39	45					36
10/9	5	6	9	15	15	20	15			12
10/10	14	9	15	22	25	18	25			18
10/11	20	28	15	13	17	20	25	13	17	19
10/12	16	12	19	18	20	25	15	18		18
10/13	21	30	22	33	22	31				27

*Data points taken at 30-second intervals after cleaning lens

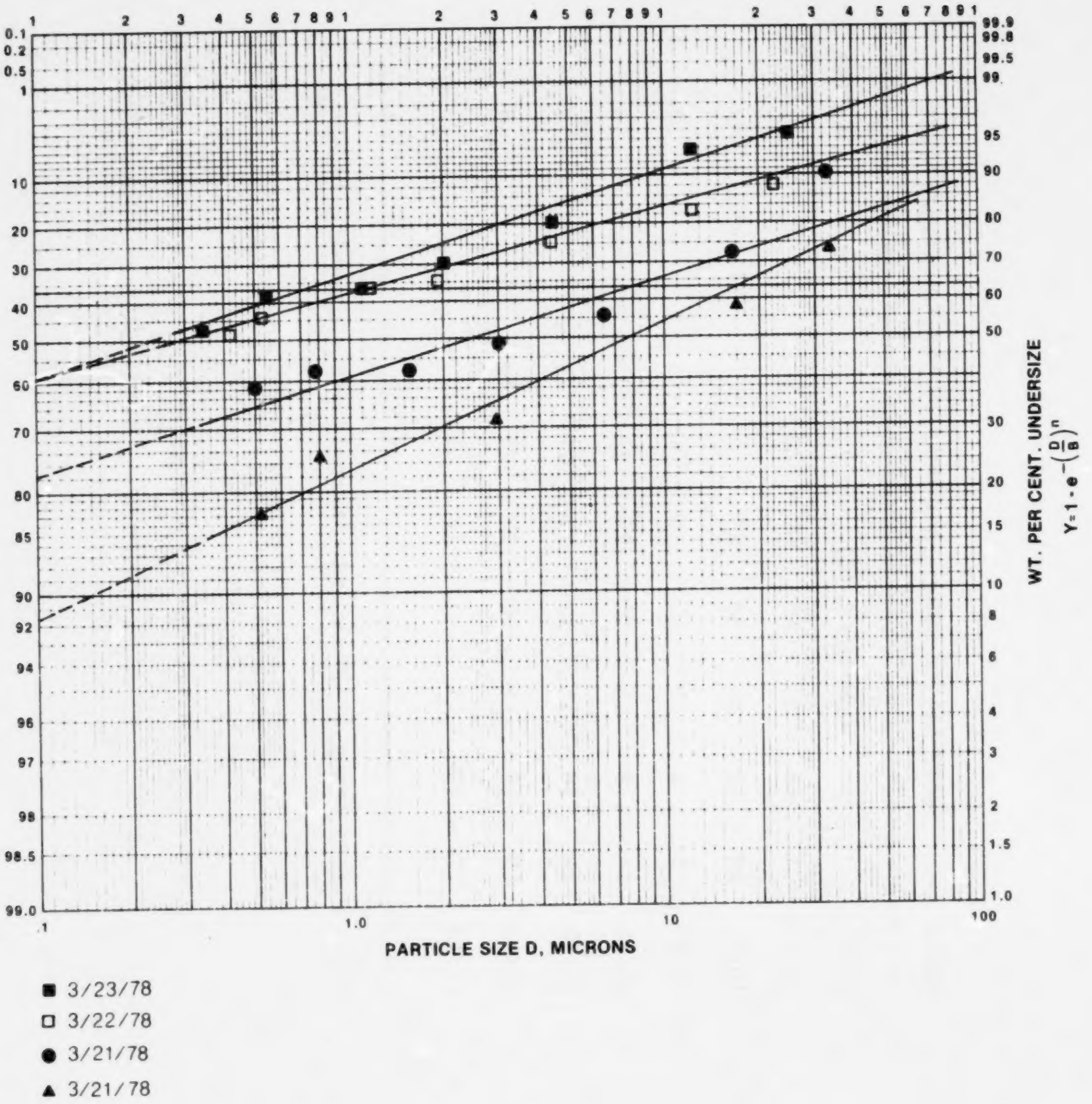

Figure A-1. Particulate size distribution of stack emissions at North Little Rock facility during March.

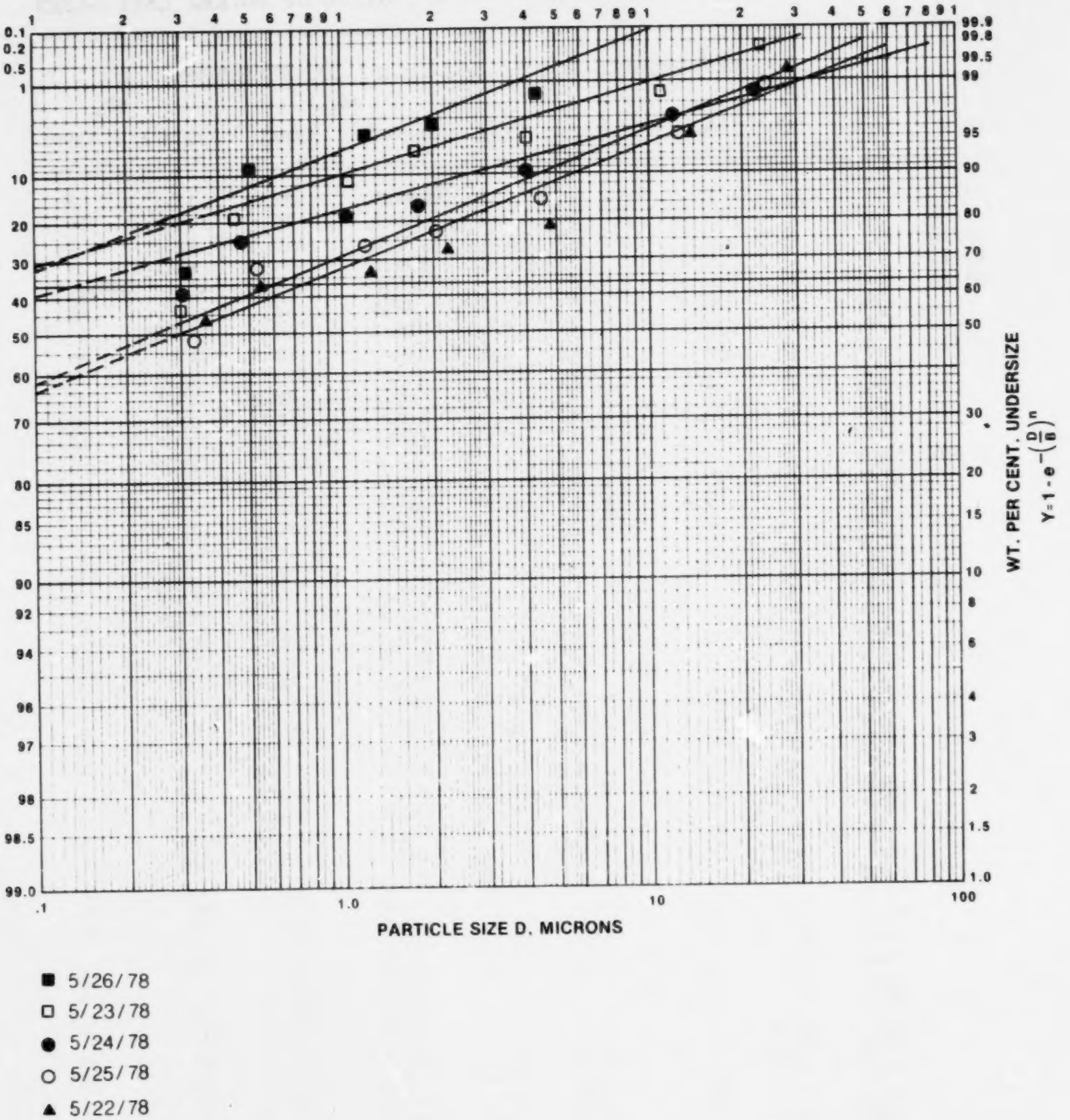

Figure A-2. Particulate size distribution of stack emissions at North Little Rock facility during May.

TABLE A-10. NORTH LITTLE ROCK HOURLY CONCENTRATION OF BOILER EXIT GASES

		NDIR monitor			Tri-gas monitor				
		CO_2	CO		O_2	NO_x		SO_x	
Date	Time	(%)	(mg/m^3)	(ppm)	(%)	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)
03/20					10.8	181.5	95	13.3	5
03/21					12.0	334.3	175	133.0	50
03/22					11.8	277.0	145	13.3	5
03/23					11.8	296.1	155	66.5	25
05/22	1000		52.9	45.6	10.1	200.6	105	<13	<5
	1500		54.9	47.3	12.7	93.6	49	<13	<5
	2300		25.8	22.2	9.2	315.2	165	88.0	33.1
05/23	0300		34.1	29.4	9.2	326.6	171	<13	<5
	0700		45.1	38.9	10.5	240.0	178	16.8	6.3
	0900		37.7	32.5	10.2	98.7	51.7	13.3	5.0
	1700		54.8	47.2	13.8	510.0	267	35.6	13.4
	2200		51.4	44.3	11.5	165.6	86.7	33.3	12.5
05/24	0400		32.5	28.0	9.7	433.6	227	27.4	10.3
	0700		42.7	36.8	10.4	391.6	205	27.9	10.5
	1400		41.6	35.9	10.8	284.6	149	41.5	15.6
	1900		61.7	53.2	11.5	251.2	131.5	25.3	9.5
	2300					76.6	40.1	<13	<5
	2400				10.8	206.5	108.1	23.4	8.8
05/25	0500				11.9	238.4	124.8	23.1	8.7
	1300				12.4	236.8	124.0	27.9	10.5
	1400				13.8	240.7	126.0	<13	<5
05/26	1100				14.5	170.8	89.4	<13	<5
	1200				14.5	139.2	72.9	<13	<5
10/09	0100	11.6	91.6	79.0	8.8	261.7	137.0	<13	<5
	0200	11.4	67.3	58.0	9.3	307.5	161.0	<13	<5
	0300	11.0	67.3	58.0	10.3	330.4	173.0	<13	<5
	0400	9.4	54.5	47.0	11.5	307.5	161.0	<13	<5
	0500	7.5	78.9	68.0	12.8	206.3	108.0	<13	<5
	0600	11.0	78.9	68.0	10.6	284.6	149.0	<13	<5
	1200	8.4	58.0	50.0	12.6	192.9	101.0	<13	<5
	1800	9.0	11.6	10.0	11.1	240.7	126.0	<13	<5
	1900	9.6	11.6	10.0	10.9	307.5	161.0	<13	<5
	2000	10.0	11.6	10.0	10.6	336.2	176.0	<13	<5
	2100	10.2	11.6	10.0	10.4	393.5	206.0	<13	<5
10/09	2200	10.4	0.0	0.0	10.1	403.0	211.0	<13	<5
	2300	10.0	0.0	0.0	10.4	450.8	236.0	<13	<5
	2400	10.0	0.0	0.0	10.4	450.8	236.0	<13	<5
10/10	0100	10.0	0.0	0.0	10.4	450.8	236.0	<13	<5
	0200	10.0	11.6	10.0	10.6	450.8	236.0	<13	<5
	0300	10.0	11.6	10.0	10.4	460.3	241.0	<13	<5
	0400	8.8	0.0	0.0	11.1	412.6	216.0	<13	<5
	0500	10.2	0.0	0.0	10.4	403.0	211.0	<13	<5
	0600	10.2	0.0	0.0	10.4	412.6	216.0	<13	<5

(continued)

TABLE A-10. (continued)

		NDIR monitor			Tri-gas monitor				
		CO_2	CO		O_2	NO_x		SO_x	
Date	Time	(%)	(mg/m^3)	(ppm)	(%)	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)
	0700	9.0	0.0	0.0	10.9	355.3	186.0	<13	<5
	0800	9.2	0.0	0.0	10.9	364.8	191.0	<13	<5
	1800	9.0	46.4	40.0	10.9	427.8	224.0	<13	<5
	1900	8.8	46.4	40.0	10.9	406.8	213.0	13.3	5.0
	2000	9.0	34.8	30.0	10.9	416.4	218.0	<13	<5
	2100	9.0	34.3	30.0	10.7	439.3	230.0	13.3	5.0
	2200	9.0	34.8	30.0	10.7	439.3	230.0	<13	<5
	2300	9.2	46.4	40.0	10.7	406.8	213.0	<13	<5
	2400	9.2	46.4	40.0	10.4	427.8	224.0	<13	<5
10/11	0100	9.2	46.4	40.0	10.4	439.3	230.0	<13	<5
	0200	9.2	34.8	30.0	10.4	416.4	218.0	<13	<5
	0300	9.2	34.8	30.0	10.4	427.8	224.0	<13	<5
	0400	9.2	46.4	40.0	10.2	427.8	224.0	<13	<5
	0500	9.4	46.4	40.0	10.2	439.3	230.0	<13	<5
	0600	9.4	46.4	40.0	10.2	427.8	224.0	<13	<5
	1800	9.0	69.6	60.0	10.4	341.9	179.0	13.3	5.0
	1900	9.2	58.0	50.0	10.7	351.4	184.0	13.3	5.0
	2000	9.4	58.0	50.0	10.7	351.4	184.0	13.3	5.0
	2100	9.4	58.0	50.0	10.9	341.9	179.0	<13	<5
	2200	9.2	58.0	50.0	10.9	341.9	179.0	<13	<5
	2300	9.4	58.0	50.0	10.9	361.0	189.0	<13	<5
	2400	9.4	58.0	50.0	10.7	380.1	199.0	<13	<5
10/12	0100	9.2	58.0	50.0	10.9	418.3	219.0	<13	<5
	0200	10.0	58.0	50.0	10.4	418.3	219.0	<13	<5
	0300	9.6	58.0	50.0	10.7	408.7	214.0	<13	<5
	0400	9.6	58.0	50.0	10.7	399.2	209.0	<13	<5
	0500	10.0	58.0	50.0	10.4	427.8	224.0	<13	<5
	0600	9.6	58.0	50.0	10.7	427.8	224.0	<13	<5
	0700	9.6	58.0	50.0	10.2	408.7	214.0	<13	<5
	1800	9.4	34.8	30.0	11.3	395.4	207.0	26.6	10.0
	1900	9.6	34.8	30.0	11.1	395.4	207.0	13.3	5.0
	2000	10.2	34.8	30.0	10.8	416.4	218.0	13.3	5.0
	2100	9.6	34.8	30.0	10.8	450.8	236.0	13.3	5.0
	2200	9.4	34.8	30.0	10.8	450.8	236.0	13.3	5.0
	2300	9.6	34.8	30.0	10.8	427.8	224.0	13.3	5.0
	2400	9.6	34.8	30.0	10.8	416.4	218.0	13.3	5.0
10/13	0100	9.6	23.2	20.0	10.8	416.4	218.0	13.3	5.0
	0200	9.4	23.2	20.0	10.8	416.4	218.0	13.3	5.0
	0300	9.2	23.2	20.0	11.1	383.9	201.0	13.3	5.0
	0400	9.4	23.2	20.0	10.8	383.9	201.0	<13	< 5
	0500	9.6	23.2	20.0	10.8	372.5	195.0	<13	< 5
	0600	9.6	23.2	20.0	11.1	404.9	212.0	<13	< 5
	0700	9.6	23.2	20.0	10.8	404.9	212.0	<13	< 5
	0800	9.2	23.2	20.0	11.1	361.0	189.0	<13	< 5
	0900	9.2	23.2	20.0	11.1	349.5	183.0	<13	< 5

TABLE A-11. NORTH LITTLE ROCK HOURLY AVERAGES OF STACK EMISSIONS

		NDIR monitor		Tri-gas monitor				
		CO		O_2	NO_x		SO_x	
Date	Time	(mg/m³)	(ppm)	(%)	(mg/m³)	(ppm)	(mg/m³)	(ppm)
03/20				16.8	95.6	50	13.3	5
03/22				18.3	105.2	55	13.3	5
03/23				16.5	95.6	50	13.3	5
05/22	1100	52.9	45.6	15.5	84.2	44	<13	2.5
	1200	61.4	62.9	15.3	117.2	61.3	<13	<5
	1300	44.5	38.4	16.1	94.9	49.6	13.3	<5
	1400	37.0	31.9	17.8	43.0	22.5	<13	<5
	1700	26.7	23.0	17.3	63.5	33.2	<13	<5
	1800	37.4	32.2	18.2	112.1	58.7	<13	<5
	1900	35.6	30.7	17.4	151.1	79.1	20.0	7.5
	2000							
	2100	36.4	31.4	15.9	131.2	68.7	33.3	12.5
	2200	24.2	20.9	16.6	109.8	57.5	31.9	12.0
	2400	27.4	23.6	16.8	112.1	58.7	16.5	6.2
05/23	0100	35.3	30.4	16.8	128.9	67.5	20.0	7.5
	0500	34.3	29.6	15.1	105.4	55.2	<13	<5
	0600	16.6	14.3	16.5	130.6	68.4	16.5	6.2
	1100	42.0	36.2	16.6	123.0	64.4	16.5	6.2
	1200	42.0	36.2	17.4	140.8	73.7	13.3	5.0
	1300	39.4	34.0	17.4	149.7	78.4	13.3	5.0
	1400	36.5	31.5	17.5	170.8	89.4	21.3	8.0
	1500	43.8	37.8	17.5	175.0	91.6	33.3	12.5
	1800	34.7	29.9	17.7	154.5	80.9	<13	<5
	1900	39.4	34.0	17.6	134.1	70.2	20.0	7.5
	2100	30.4	26.2	17.2	56.7	29.7	<13	<5
	2300	23.2	20.0	17.4	33.6	17.6	<13	<5
	2400	30.0	25.9	16.7	81.6	42.7	<13	<5
05/24	0100	35.8	30.9	16.7	115.6	60.5	19.4	7.3
	0300	23.1	19.9	16.8	138.7	72.6	<13	<5
	0500	31.8	27.4	17.2	62.5	32.7	18.6	7.0
	0600	33.5	28.9	17.3	63.0	33.0	13.3	5.0
	0900	25.4	21.9	17.1	138.7	72.6	<13	<5
	1000	25.3	21.8	17.1	104.5	54.7	<13	<5
	1100	35.8	30.9	18.0	121.5	63.6	<13	<5
	1200	42.0	36.2	17.3	113.1	59.2	<13	<5
	1300	23.8	20.5	16.5	82.1	43.0	<13	<5
	1500	54.4	46.9	18.3	100.5	52.6	21.3	8.0
	1600	42.0	36.2	18.2	55.2	28.9	16.5	6.2
	1700	38.3	33.0	18.4	52.5	27.5	16.5	6.2
	1800	24.7	21.3	17.1	70.3	36.8	<13	<5
	2100			15.8	56.5	29.6	<13	<5
	2200			16.9	127.8	66.9	<13	<5
	2300			15.1	0.0	0.0	<13	<5

(continued)

TABLE A-11. (continued)

		Tri-gas monitor				
		O_2	NO_x		SO_x	
Date	Time	(%)	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)
05/25	0100	15.9	98.0	51.3	<13	<5
	0300	18.2	0.0	0.0	20.0	7.5
	0600	17.9	75.4	39.5	<13	<5
	0700	19.0	42.8	22.4	16.8	6.3
	0800	16.7	61.5	32.2	<13	<5
	1000	17.3	90.3	47.3	<13	<5
	1100	16.8	27.3	14.3	<13	<5
	1200	18.3	78.7	41.2	<13	<5
	1500	18.1	98.9	51.8	<13	<5
	1600	17.7	84.8	44.4	<13	<5
05/26	0900	17.3	81.2	42.5	<13	<5
	1000	15.9	119.0	62.3	<13	<5
	1300	16.6	64.2	33.6	<13	<5
	1400	16.6	95.7	50.1		
10/5	1600	17.3	114.6	60.0	<13	<5
	1700	17.0	133.7	70.0	<13	<5
	1800	17.5	124.2	65.0	<13	<5
	1900	17.5	133.7	70.0	<13	<5
	2000	17.5	133.7	70.0	<13	<5
	2100	17.5	133.7	70.0	<13	<5
	2200	17.8	124.2	65.0	<13	<5
	2300	17.8	114.6	60.0	<13	<5
	2400	17.8	86.0	45.0	<13	<5
10/6	0100	17.8	57.3	30.0	<13	<5
	0200	17.5	76.4	40.0	<13	<5
	0300	17.5	76.4	40.0	<13	<5
	0400	17.5	57.3	30.0	<13	<5
	0500	17.5	86.0	45.0	<13	<5
	0600	17.5	76.4	40.0	<13	<5
	0700	17.3	76.4	40.0	<13	<5
	1000	16.9	95.5	50.0	<13	<5
	1100	16.9	114.6	60.0	<13	<5
	1200	16.7	124.2	65.0	<13	<5
	1300	17.4	114.6	60.0	<13	<5
	1400	17.7	105.1	55.0	<13	<5
	1500	17.7	105.1	55.0	<13	<5
	1600	17.7	86.0	45.0	<13	<5
	1700	17.7	86.0	45.0	<13	<5
	1800	17.7	86.0	45.0	<13	<5
	1900	17.4	95.5	50.0	<13	<5
	2000	17.2	76.4	40.0	<13	<5
	2100	17.2	76.4	40.0	<13	<5

(continued)

TABLE A-11. (continued)

		NDIR monitor			Tri-gas monitor				
		CO_2	CO		O_2	NO_x		SO_x	
Date	Time	(%)	(mg/m^3)	(ppm)	(%)	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)
10/9	0900	5.0	34.5	30	15.8	124.2	65.0	<13	<5
	1000	6.0	41	40	14.8	152.8	80.0	<13	<5
	1100	6.8	41	40	13.8	181.5	95.0	<13	<5
	1300	5.2	34.5	30	15.3	124.2	65.0	<13	<5
	1400	5.2	34.5	30	15.6	124.2	65.0	<13	<5
	1500	5.2	34.5	30	15.6	114.6	60.0	<13	<5
	1600	5.0	34.5	30	15.8	114.6	60.0	<13	<5
10/10	1000	4.8	<11.5	<10	15.7	171.9	90.0	<13	<5
	1100	5.0	11.5	10	16.2	162.4	85.0	<13	<5
	1200	5.2	11.5	10	15.9	162.4	85.0	<13	<5
	1300	5.5	23	20	16.2	192.9	101.0	<13	<5
	1400	5.2	23	20	15.9	183.4	96.0	<13	<5
	1500	5.2	34.5	30	16.4	192.9	101.0	<13	<5
	1600	5.0	23	20	16.6	183.4	96.0	<13	<5
10/11	0800	3.9	34.5	30	16.8	143.3	75.0	<13	<5
	0900	4.0	34.5	30	17.1	143.3	75.0	<13	<5
	1000	3.9	34.5	30	17.1	143.3	75.0	<13	<5
	1100	3.9	34.5	30	16.8	152.8	80.0	<13	<5
	1200	3.8	23	20	17.1	133.7	70.0	<13	<5
	1300	3.9	23	20	17.1	112.7	59.0	<13	<5
	1400	3.9	23	20	16.8	112.7	59.0	<13	<5
	1500	3.6	23	20	17.1	122.2	64.0	<13	<5
	1600	3.6	23	20	17.3	122.2	64.0	<13	<5
10/12	0900	3.9	23	20	16.6	162.4	85.0	<13	<5
	1000	3.9	23	20	16.6	141.3	74.0	<13	<5
	1100	3.9	34.5	30	16.9	152.8	80.0	<13	<5
	1200	4.0	34.5	30	16.9	152.8	80.0	<13	<5
	1300	4.0	34.5	30	17.1	141.3	74.0	<13	<5
	1400	3.9	34.5	30	17.4	141.3	74.0	<13	<5
10/13	1000	3.2	34.5	30	18.0	158.5	83.0	<13	<5
	1100	3.5	34.5	30	17.8	202.5	106.0	<13	<5
	1200	3.8	34.5	30	17.5	191.0	100.0	<13	<5
	1300	3.8	34.5	30	17.2	202.5	106.0	<13	<5
	1400	3.8	46	40	17.5	213.9	112.0	<13	<5
	1500	3.8	34.5	30	17.8	170.0	89.0	<13	<5
	1700	8.9	46	40					
	1800	8.7	46	40					
	1900	8.7	46	40					
	2000	8.7	46	40					

TABLE A-12. NORTH LITTLE ROCK BOILER STACK GASEOUS EMISSION*

Date	Chlorides		Fluorides		NO_x		SO_x	
	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)
03/21	609.9	420.8	1.7	2.2			136.6	52.2
03/21	323.9	223.5	1.9	2.4	86.5	46.0		
03/22	293.8	202.7	1.6	2.1				
03/22	217.0	149.7	2.6	3.4	75.2	40.0	93.5	35.7
03/23	263.9	182.1	1.6	2.0				
03/23	359.6	248.1	4.3	5.5			60.7	23.2
05/22	31.2	21.5	1.7	2.2			73.0	27.9
05/22	19.4	13.4	1.7	2.2	23.3	12.4	56.0	21.4
05/23	22.2	15.3	0.6	0.8	105.6	56.2	62.6	23.9
05/24	34.9	24.1	1.6	2.0			95.3	36.4
05/25	22.3	15.4	0.9	1.1			55.0	21.0
10/10	193.3	133.4	0.9	1.1	194.8	102.0	105.2	40.2
10/10							100.5	38.4
10/10							99.2	37.9
10/10							5.0	1.9
10/11	154.1	106.3	0.9	1.2	162.0	84.8	63.9	24.4
10/11							5.5	2.1
10/12	127.4	87.9	1.2	1.5			45.3	17.3
10/12							44.8	17.1
10/12							4.5	1.7
10/12	144.5	99.7	0.5	0.6			42.9	16.4
10/12							44.8	17.1
10/12							3.7	1.4
10/13					150.0	78.3		
10/13					158.7	83.1		
Average	187.8	129.6	1.6	2.0	119.5	62.9	59.9	22.9
Standard Deviation	$\sigma = 159.6$		$\sigma = 0.9$		$\sigma = 53.0$		$\sigma = 36.7$	

*Using wet chemistry techniques on impinger solutions.

TABLE A-13. NORTH LITTLE ROCK STACK GASES HYDROCARBON ANALYSIS

Date	Time	C_1 (ppm)	C_2 (ppm)	C_3 (ppm)	Total (ppm)
03/23	1030	1.4		1.0	
	1050	1.8	0.2	1.0	
	1100	1.7		1.0	
	1120	1.6		1.0	
	1130	1.6		1.0	
05/25	1645				2.5
	1655	3.0			
	1700	1.0			
05/26	1015				2.1
	1022				2.1
	1255	1.5			
	1430	1.0			
10/11	1303	30.0	10.0*		
10/11	1710	20.0	5.0*		
10/12	0910	15.0	5.0*		

* Greater than C_1

TABLE A-14. NORTH LITTLE ROCK BOILER GASES HYDROCARBON ANALYSIS

Date	Time	C_1 (ppm)	C_2 (ppm)	C_3 (ppm)	C_4 (ppm)	Total (ppm)
03/23	1200	0.6		1.1		
	1210	0.3		1.1		
	1440			0.6		
	1450	0.6				
	1510			0.5		
	1600	0.3		0.5		
	1620	0.3		0.5		
	1640	0.3	0.2	0.2	0.5	
05/26	1124					17.0
	1150					13.3
	1243					13.7

TABLE A-15. NORTH LITTLE ROCK BOILER WATER GENERAL PARAMETERS

	Concentration found	
Parameter	Makeup Water	Blowdown Water
pH	8.7	12.4
Acidity	0.0 mg/ℓ	0.0 mg/ℓ
Alkalinity	45.3 mg/ℓ	1050 mg/ℓ
Total dissolved solids	5.0 mg/ℓ	2800 mg/ℓ
Total suspended solids	15.0 mg/ℓ	596 mg/ℓ
Total solids	20.0 mg/ℓ	3400 mg/ℓ
Total Kjeldahl nitrogen	0.05 mg/ℓ	1.34 mg/ℓ
Hardness as $CaCO_3$	40 mg/ℓ	24.0 mg/ℓ
Chloride	5.7 mg/ℓ	253 mg/ℓ
Fluoride	1.23 mg/ℓ	-

TABLE A-16. MARYSVILLE DAILY SYSTEM EFFICIENCY BY HEAT LOSS METHOD

	Operational mode	
Date	Steady state %	With burndown %
4/24	68.58	42.21
4/25	65.08	38.17
4/26	63.41	40.40
4/27	66.32	31.93
7/17	65.75	29.90
7/18	62.15	34.68
7/19	67.23	36.28
7/20	67.21	32.43
8/21	60.18	8.62
8/22	37.47	25.78
8/23	54.11	23.78
8/24	47.64	23.20

TABLE A-17. MARYSVILLE REFUSE ULTIMATE ANALYSIS BY COMPONENT*

Element	Percent of total by weight (dry basis)	
	Wood	Paper
Hydrogen	7.08	6.85
Carbon	53.74	49.71
Nitrogen	0.58	4.54
Oxygen	38.08	36.13
Sulfur	0.04	0.19
Chlorine	N.D.	N.D.
Ash	0.48	2.58
Total	100.00	100.00

* Analysis of samples from 8/22/78.

N.D. None Detected

TABLE A-18. MARYSVILLE PARTICULATE EMISSIONS DATA

Date	Particulate		CO	Particulate*	
	(g/dscm)	(gr/dscm)	(%)	(g/dscm)	(gr/dscf)
07/17	0.0764	0.0334	7.2	0.1275	0.0557
07/18	0.2124	0.0928	10.0	0.2538	0.1113
07/19	0.0666	0.0291	10.5	0.0762	0.0333
07/19	0.0766	0.0335	10.5	0.0876	0.0383
07/20	0.0698	0.0305	10.2	0.0822	0.0359
07/20	0.0643	0.0281	10.2	0.0757	0.0331
07/21	0.0842	0.0368	9.5	0.1064	0.0465
07/21	0.1055	0.0461	9.5	0.1332	0.0582
07/21	0.0636	0.0278	9.5	0.0803	0.0351
08/18	0.1288	0.0563	9.0	0.1719	0.0751
08/21	0.0902	0.0394	6.5	0.1664	0.0727
08/24	0.1023	0.0447	5.0	0.2455	0.1073
08/24	0.0860	0.0376	3.4	0.3037	0.1327
08/24	0.0675	0.0295	3.4	0.2382	0.1041
08/25	0.0664	0.0290	5.8	0.1373	0.0600
08/25	0.0735	0.0321	5.8	0.1519	0.0664
Average	0.0896	0.0392	7.7	0.1586	0.0693
Standard Deviation	σ = 0.0362			σ = 0.0825	

*Corrected to 12% CO_2

TABLE A-19. MARYSVILLE BURNDOWN PARTICULATE EMISSION DATA

Date	Particulate (g/scm)	Particulate (gr/scf)	CO_2 (%)	Particulate* (g/scm)	Particulate* (gr/scf)
08/22	0.2355	0.1029	1.8	1.5698	0.6860
08/23	0.0169	0.0074	1.8	0.1128	0.0493
08/23	0.0973	0.0425	0.2	5.8352	2.5500

*Corrected to 12% CO_2

TABLE A-20. PARTICULATE EMISSIONS SUMMARY DATA SHEET

SYSTECH
Systems Technology Corporation
245 North Valley Road
Xenia, Ohio 45385

JOB: Rockwell International (Kelley Incinerator)

GENERAL						
Date 4/24 - 4/28/78	4/24/78	4/25/78	4/26/78	4/27/78	4/28/78	
Emission Source Plant Incinerator (Kelley)						
Barometric Pressure (ins. Hg)	28.87	28.82	28.90	29.40	29.65	
Specific Gravity of Gases Referred to Air	27.28	28.206	27.986	28.167	27.791	
Coal Usage Rate During Test (lbs./hr.)						
Coal Heat Value (BTU/lb.)						
BTU Input (BTU/hr.)						
Average Steam Load (lbs./hr.)						
GAS FLOW DATA						
Stack Area (ft^2)	3.41					
Avg. Velocity at Stack Conditions (FPM)	1103.	795.	746.	774.	646.	
Flow Rate at Stack Conditions (CFM)	3762.	2712.	2545.	2639.	2205.	
Stack Temperature (°F)	150°	196°	227°	219°	187°	
Flow Rate at Standard Conditions (SCFM)	3154.	2110.	1896.	2024.	1790.	
PARTICULATE EMISSION DATA						
Total Particulate Collected (mg)	1056.6	1033.24	944.8	883.2	1463.9	
Volume Dry Gas Sampled at Std. Cond. (SCF)	57.46	51.09	44.11	47.42	21.80	
Volume Water Vapor Sampled at Std. Cond. (SCF)	15.03	6.873	7.47	6.518	4.08	
Total Sampled Volume at Std. Cond. (SCF)	72.49	57.96	51.63	53.94	25.88	
Particulate Concentration (gr./SCF)	0.2832	0.3115	0.3294	0.2868	1.0352	
Particulate Concentration (lbs./SCF) × 10^{-5}	4.04	4.45	4.7	4.10	1.48 × 10^{-4}	
Particulate Emission Rate (lbs./hr.)	7.647	5.636	5.348	4.981	15.898	
Particulate Emission Rate (lbs./10^6 BTU)						
Percent Isokinetic Sample (%)	**102	*122	*115	*118	*122	
MISCELLANEOUS DATA						
* Not acceptable - Void	*Void					
** Acceptable Run % Isokinetic +, -, 10% of 100%					***	

*** Test time was total of 52.5 minutes

Conditions of operation very unusual due to plant taking heating demand off boiler for plant heat and putting plant air conditioner unit on line, which is but a seasonal operation. Refractory dust in the emissions.

(continued)

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Systems Technology Corporation
245 North Valley Road
Xenia, Ohio 45385

TABLE A-20. (continued)

JOB: Rockwell International (Kelley Incinerator)

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
GENERAL						
Date	7/17/78	7/18/78	7/19/78	7/19/78	7/20/78	7/20/78
Emission Source	Kelley Inc	Kelley Inc	Kelley Inc	Kelley Inc	Kelley Inc	Kelley Inc
Barometric Pressure (ins. Hg)	28.735	28.735	30.12	30.12	29.05	29.05
Specific Gravity of Gases Referred to Air	27.7	27.8	28.2	28.4	28.2	28.2
Coal Usage Rate During Test (lbs./hr.)						
Coal Heat Value (BTU/lb.)						
BTU Input (BTU/hr.)						
Average Steam Load (lbs./hr.)						
GAS FLOW DATA						
Stack Area (ft^2)	3.41					
Avg. Velocity at Stack Conditions (FPM)	2743.18	947.665	1003.129	908.535	1047.764	1040.0636
Flow Rate at Stack Conditions (CFM)	9350.814	3231.539	3420.669	3098.105	3572.875	3546.6168
Stack Temperature (°F)	237.2	277.0	276.0	287.0	286.0	291.0
Flow Rate at Standard Conditions (SCFM)	6826.842	2231.874	2479.733	2212.825	2464.574	2430.173
PARTICULATE EMISSION DATA						
Total Particulate Collected (mg)	121.9	430.7	156.0	159.3	160.7	142.6
Volume Dry Gas Sampled at Std. Cond. (SCF)	56.23	71.50	82.65	73.16	81.03	78.202
Volume Water Vapor Sampled at Std. Cond. (SCF)	11.32	12.89	14.9	11.23	14.03	13.011
Total Sampled Volume at Std. Cond. (SCF)	67.56	84.39	97.6	84.39	95.06	91.2
Particulate Concentration (gr./SCF)	0.0333	0.0928	0.0290	0.0335	0.0305	0.0280
Particulate Concentration (lbs./SCF) x 10^{-6}	4.77	1.325	4.15	4.79	4.36	4.01
Particulate Emission Rate (lbs./hr.)	1.62	1.50	0.52	0.55	0.549	0.50
Particulate Emission Rate (lbs./10^6 BTU)						
Percent Isokinetic Sample (%)	99.0	94.5	98.5	95.3	96.4	93.8
MISCELLANEOUS DATA						
*See attached note	*					

(continued)

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TABLE A-20.(continued)

SYSTECH® Systems Technology Corporation
245 North Valley Road
Xenia, Ohio 45385

JOB: Rockwell International (Kelley Incinerator)

	Run 7	Run 8	Run 9			
GENERAL						
Date	7/21/78	7/21/78	7/21/78			
Emission Source	Kelley Inc	Kelley Inc	Kelley Inc			
Barometric Pressure (ins. Hg)	29.0	29.0	29.0			
Specific Gravity of Gases Referred to Air	28.31	28.28	28.30			
Coal Usage Rate During Test (lbs./hr.)						
Coal Heat Value (BTU/lb.)						
BTU Input (BTU/hr.)						
Average Steam Load (lbs./hr.)						
GAS FLOW DATA						
Stack Area (ft^2)	3.41					
Avg. Velocity at Stack Conditions (FPM)	993.999	1059.245	1011.125			
Flow Rate at Stack Conditions (CFM)	3389.537	3612.025	3447.936			
Stack Temperature (°F)	286.0	289.0	291.0			
Flow Rate at Standard Conditions (SCFM)	2334.082	2477.328	2358.489			
PARTICULATE EMISSION DATA						
Total Particulate Collected (mg)	187.1	232.4	140.9			
Volume Dry Gas Sampled at Std. Cond. (SCF)	78.32	77.58	78.07			
Volume Water Vapor Sampled at Std. Cond. (SCF)	12.20	12.32	12.30			
Total Sampled Volume at Std. Cond. (SCF)	90.52	89.90	90.37			
Particulate Concentration (gr./SCF)	0.0367	0.0461	0.0277			
Particulate Concentration (lbs./SCF) $\times 10^{-6}$	5.25	6.59	3.97			
Particulate Emission Rate (lbs./hr.)	0.63	0.84	0.48			
Particulate Emission Rate (lbs./10^6 BTU)						
Percent Isokinetic Sample (%)	96.9	90.7	95.8			
MISCELLANEOUS DATA						

(continued)

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TABLE A-20.(continued)

SYSTECH®
Systems Technology Corporation
245 North Valley Road
Xenia, Ohio 45385

JOB: Rockwell International

GENERAL						
Date	8/23/78	8/23/78	8/24/78	8/24/78	8/24/78	8/25/78
Emission Source						
Barometric Pressure (ins. Hg)	29.1	29.1	29.0	29.0	29.0	28.95
Specific Gravity of Gases Referred to Air	28.85	28.04	28.48	28.08	27.58	28.16
Coal Usage Rate During Test (lbs./hr.)						
Coal Heat Value (BTU/lb.)						
BTU Input (BTU/hr.)						
Average Steam Load (lbs./hr.)						
GAS FLOW DATA Test Start	3:00 a.m.	6:45 a.m.	8:00 a.m.	10:30 a.m.	2:13 p.m.	8:02 a.m.
Stack Area (ft^2)	3.41					
Avg. Velocity at Stack Conditions (FPM)	665.55	1015.9	1060.544	1022.78	1044.23	1069.71
Flow Rate at Stack Conditions (CFM)	2235.43	3464.2	3616.45	3487.69	3560.83	3647.72
Stack Temperature (°F)	217	353	367	278	300	370.5
Flow Rate at Standard Conditions (SCFM)	1702.09	2196.5	2246.43	2427.7	2406.87	2252.4
PARTICULATE EMISSION DATA						
Total Particulate Collected (mg)	30.4	202.3	224.5	196.5	148.7	145.8
Volume Dry Gas Sampled at Std. Cond. (SCF)	63.72	73.34	77.29	80.38	77.72	77.34
Volume Water Vapor Sampled at Std. Cond. (SCF)	1.138	5.71	6.76	8.86	13.06	10.1
Total Sampled Volume at Std. Cond. (SCF)	64.86	79.05	84.05	89.24	90.78	87.44
Particulate Concentration (gr./SCF)	0.0073	0.04247	0.0447	0.0376	0.0294	0.0290
Particulate Concentration (lbs./SCF) x 10^{-6}	1.05	6.07	6.39	5.38	4.21	4.15
Particulate Emission Rate (lbs./hr.)	0.105	0.742	0.792	0.705	0.52	0.496
Particulate Emission Rate (lbs./10^6 BTU)						
Percent Isokinetic Sample (%)	*95.3	*90.0	*93.5	*91.9	*94.3	*97.0
MISCELLANEOUS DATA						
*Acceptable Test						
	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12

(continued)

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TABLE A-20. (continued)

SYSTECH®
Systems Technology Corporation
245 North Valley Road
Xenia, Ohio 45385

JOB: Rockwell International

GENERAL						
Date	8/25/78					
Emission Source						
Barometric Pressure (ins. Hg)	28.95					
Specific Gravity of Gases Referred to Air	28.03					
Coal Usage Rate During Test (lbs./hr.)						
Coal Heat Value (BTU/lb.)						
BTU Input (BTU/hr.)						
Average Steam Load (lbs./hr.)						
GAS FLOW DATA Test Start	12:27 p.m.					
Stack Area (ft^2)	3.41					
Avg. Velocity at Stack Conditions (FPM)	1081.4					
Flow Rate at Stack Conditions (CFM)	3687.6					
Stack Temperature (°F)	300					
Flow Rate at Standard Conditions (SCFM)	2488.26					
PARTICULATE EMISSION DATA						
Total Particulate Collected (mg)	172.7					
Volume Dry Gas Sampled at Std. Cond. (SCF)	82.81					
Volume Water Vapor Sampled at Std. Cond. (SCF)	12.1					
Total Sampled Volume at Std. Cond. (SCF)	94.91					
Particulate Concentration (gr./SCF)	0.0321					
Particulate Concentration (lbs./SCF) x 10^{-6}	4.59					
Particulate Emission Rate (lbs./hr.)	0.59					
Particulate Emission Rate (lbs./10^6 BTU)						
Percent Isokinetic Sample (%)	*95.3					
MISCELLANEOUS DATA						
*Acceptable Test						
	Run 13					

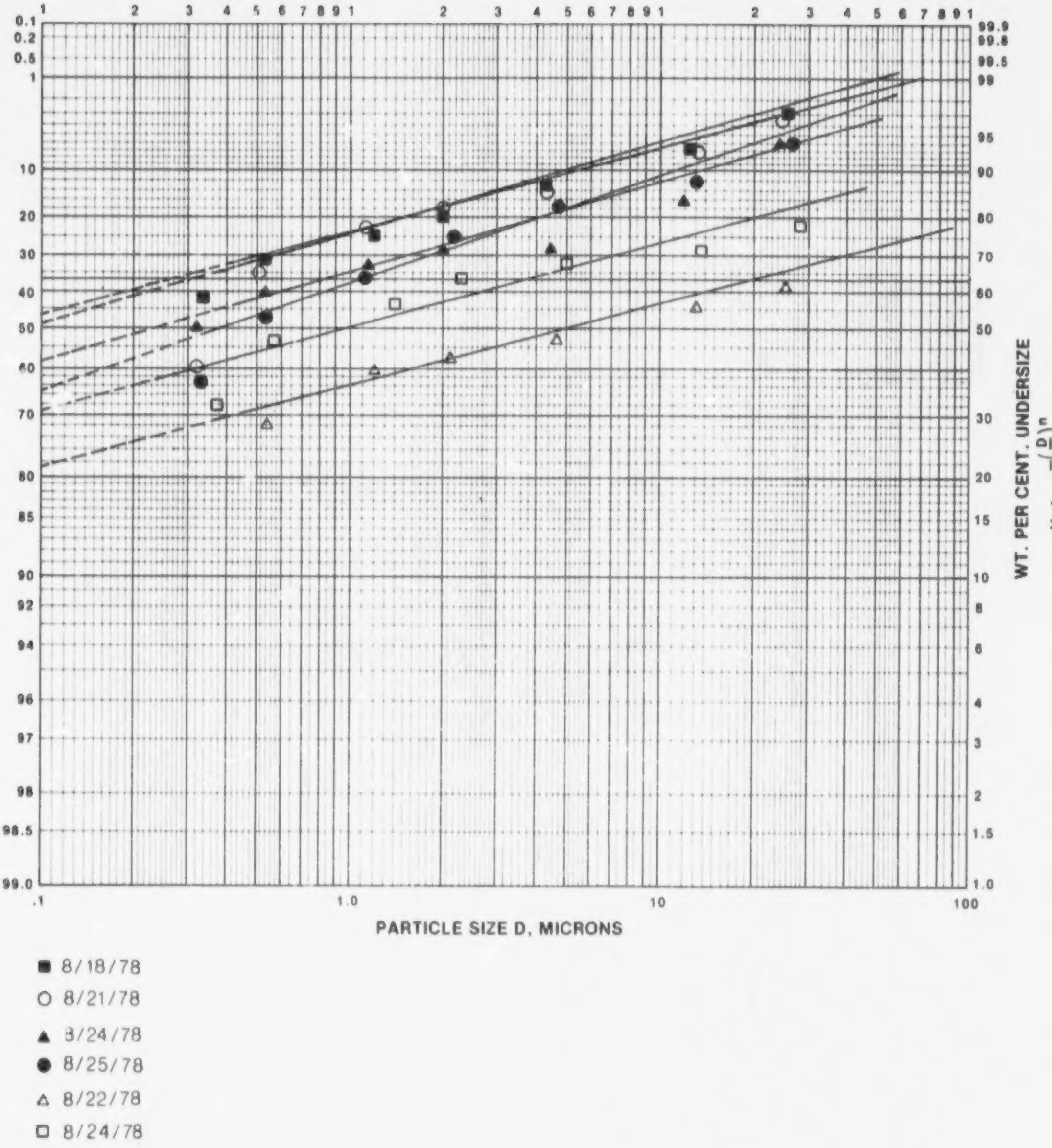


Figure A-3. Particulate size distribution of stack emissions at Marysville facility during August.

TABLE A-21. MARYSVILLE HOURLY AVERAGES OF STACK GAS COMPOSITION

		NDIR monitor		Tri-gas monitor				
		CO		O_2	NO_x		SO_x	
Date	Time	(ppm)	(mg/m^3)	(%)	(ppm)	(mg/m^3)	(ppm)	(mg/m^3)
04/25	0900	44	51	12.6	36	69	5	13
	1000	22	26	12.9	42	80	<5	13
	1100	39	45	13.6	28	53	<5	13
	1200	32	37	13.7	33	63	<5	<13
	1300	45	52	14.7	25	48	<5	<13
04/26	0900	50	58	13.4	28	53	<5	<13
	1000	53	61	14.4	23	44	<5	<13
	1100	29	34	17.8	>5	<10	<5	<13
	1200	47	55	17.5	>5	<10	<5	<13
	1300	70	81	17.2	10	19	<5	<13
	1400	37	43	13.5	33	63	<5	<13
	1500	35	41	15.2	13	25	<5	<13
04/27	0900	59	68	13.9	19	36	14	37
	1000	>1000	>1160	12.2	57	109	14	37
	1100	140	162	14.9	40	76	<5	<13
	1200	63	73	15.2	18	34	5	13
	1300	84	97	12.5	100	191	<5	<13
	1400	57	66	12.9	53	101	<5	<13
04/28	0800	47	55	10.7	57	109	<5	<13
	0900	53	61	13.0	40	76		
	1000	>1000	>1160	12.2	34	65		
	1100	56	65	13.8	39	74		
	1200	47	55	13.4	45	86		
	1300	46	53	15.3	21	40		
	1400		53	14.2	32	61		
07/17	1500			11.3	23	44	28	74
	1600			18.5	20	38	22	59
	1700			13.9	35	67	25	67
	1800			14.1	33	63	23	61
	1900			13.9	35	67	30	80
	2000			14.8	35	67	17	45
	2100			15.2	28	53	15	40
	2200			14.5	33	63	15	40
	2300	>1000	> 1160	16.3	23	44	17	45
	2400	319	370	17.2	16	31	12	32

Continued

TABLE A-21. (continued)

		NDIR monitor		Tri-gas monitor				
		CO		O_2	NO_x		SO_x	
Date	Time	(ppm)	(mg/m^3)	(%)	(ppm)	(mg/m^3)	(ppm)	(mg/m^3)
07/18	0100	248	288	17.3	11	21	9	24
	0200	163	189	17.6	9	17	9	24
	0300	81	94	17.8	8	15	8	21
	0400	25	29	18.1	7	13	7	19
	0500	22	26	18.3	6	11	6	16
	0600	19	22	18.6	6	11	6	16
	0700	126	146	16.9	22	42	14	37
	0900	>1000	>1160	13.9	19	36	20	53
	1000	>1000	>1160	13.3	92	176	31	82
	1100	>1000	>1160	13.9	75	143	21	56
	1200			14.0	49	94	9	24
	1300			9.9	125	239	11	29
	1400	56	65	12.6	46	88	<5	<13
	1500			15.5	25	48	<5	<13
07/19	1000	41	48	11.6	68	130	<5	<13
	1100			13.8	80	153	<5	<13
	1200			12.4	57	109	<5	<13
	1300			13.8	63	120	<5	<13
	1400	50	58	11.8	66	126	<5	<13
	1500	>1000	>1160	15.1	50	96	<5	<13
	1700	100	116	13.3	48	92	<5	<13
	1800	95	110	13.9	50	96	<5	<13
	1900			12.9	60	115	<5	<13
	2000	>1000	>1160	14.7	48	92	5	13
	2100			13.1	63	120	5	13
	2200			13.5	64	122	<5	<13
	2300	>1000	>1160	16.2	35	67	<5	<13
	2400	>1000	>1160	17.4	19	36	<5	<13
07/20	0100	436	506	17.7	15	29	<5	<13
	0200	324	376	17.6	12	23	<5	<13
	0300	249	289	17.4	12	23	<5	<13
	0400	286	332	17.4	11	21	<5	<13
	0500	214	248	17.6	9	17	<5	<13
	0600	411	477	17.6	8	15	<5	<13
	0700	203	235	15.2	21	40	<5	<13
	0800			6.8	21	40	<5	<13
	0900	29	34	5.4	29	55	<5	<13

Continued

TABLE A-21. (continued)

Date	Time	NDIR monitor		Tri-gas monitor				
		CO		O_2	NO_x		SO_x	
		(ppm)	(mg/m^3)	(%)	(ppm)	(mg/m^3)	(ppm)	(mg/m^3)
07/20	1000			11.2	47	90	6	16
	1100	49	57	12.8	50	96	<5	<13
	1200	71	82	11.7	57	109	<5	<13
	1300			11.0	80	153	<5	<13
	1400	61	71	12.1	65	124	5	13
	1500	17	20	5.9	30	57	<5	<13
	1600	53	61	7.4	8	15	<5	<13
	1700	58	67	13.3	19	36	<5	<13
	1800	32	37	13.6	18	34	<5	<13
	1900	34	39	14.1	16	31	<5	<13
	2000	31	36	14.3	11	21	<5	<13
	2100	28	32	12.0	17	32	<5	<13
	2200	39	45	13.7	18	34	<5	<13
	2300	22	26	15.7	8	15	<5	<13
	2400	20	23	16.6	8	15	<5	<13
07/21	0100	18	21	16.8	6	11	<5	<13
	0200	21	24	16.8	6	11	<5	<13
	0300	23	27	16.9	6	11	<5	<13
	0400	23	27	17.0	6	11	<5	<13
	0500	27	31	17.2	6	11	<5	<13
	0600	31	36	17.3	6	11	<5	<13
	0700			14.8	8	15	<5	<13
	0800			15.2	16	31	<5	<13
	0900			14.1	12	23	<5	<13
	1000	126	146	11.9	25	48	<5	<13
	1100	57	66	13.0	18	34	<5	<13
	1200	44	51	13.6	16	31	<5	<13
	1300	139	161	11.9	24	46	<5	<13
	1400	214	248	13.9	14	27	<5	<13
08/21	1300			13.8	40	76	8	21
	1400	72	84	14.1	48	92	<5	<13
	1500	94	109	13.2	51	97	5	13
	1600	37	43	15.7	23	44	<5	<13
	1700	32	37	17.3	7	13	<5	<13
	1800	171	198	16.3	15	29	<5	<13
	1900	33	38	17.4	9	17	<5	<13
	2000	18	21	17.5	5	10	<5	<13
	2100	119	138	16.4	9	17	<5	<13

Continued

TABLE A-21. (continued)

		NDIR monitor		Tri-gas monitor				
		CO		O_2	NO_x		SO_x	
Date	Time	(ppm)	(mg/m^3)	(%)	(ppm)	(mg/m^3)	(ppm)	(mg/m^3)
08/21	2300	99	115	16.1	16	31	<5	<13
	2400	15	17	17.1	12	23	<5	<13
08/22	0100	11	13	18.4	6	11	<5	<13
	0200	7	8	18.5	4	8	<5	<13
	0300	9	10	18.8	1	2	<5	<13
	0400	9	10	19.1	0	0	<5	<13
	0500	52	60	16.5	15	29	<5	<13
	0600	25	29		15	29	<5	<13
	0800	100	116	14.6	30	57	<5	<13
	0900	73	85	13.9	40	76	<5	16
	1000	54	63	14.9	47	90	<5	<13
	1100	53	61	16.0	23	44	<5	<13
	1200	107	124	18.1	9	17	<5	<13
	1300	86	100	17.8	15	29	13	36
	1400	248	287	15.9	21	40	7	19
	1500	253	293	15.8	25	48	5	13
	1600	25	29	18.3	11	21	<5	<13
	1700	106	123	17.6	15	29	<5	<13
	1800	15	17	19.2	9	17	<5	<13
	1900	33	38	19.4	5	10	<5	<13
	2000	60	70	19.4	4	7	<5	<13
	2100	97	113	19.7	3	6	<5	<13
	2300	181	210	19.8	3	6	<5	<13
	2400	313	363	20.1	3	6	<5	<13
08/23	0100	229	266	20.1	3	6	<5	<13
	0200	229	266	20.0	3	6	<5	<13
	0300	251	291	19.9	3	6	<5	<13
	0400	237	275	19.8	3	6	<5	<13
	0500	225	261	20.0	3	6	<5	<13
	0600	233	270	20.3	3	6	<5	<13
	0700	320	371	17.6	15	29	5	13
	0800	60	70	15.5	31	59	<5	<13
	0900	35	41	13.9	38	73	<5	<13
	1000	30	35	13.7	42	80	<5	<13
	1100	21	24	16.0	22	42	<5	<13
	1200	20	23	13.9	57	109	<5	<13
	1300	23	27	13.5	54	103	5	13
	1400	36	42	12.4	68	130	6	16

Continued

TABLE A-21. (continued)

		NDIR monitor		Tri-gas monitor				
		CO		O_2	NO_x		SO_x	
Date	Time	(ppm)	(mg/m^3)	(%)	(ppm)	(mg/m^3)	(ppm)	(mg/m^3)
08/23	1500	16	19	15.4	35	67	<5	<13
	1600	20	23	17.9	14	27	<5	<13
	1700	31	36	16.2	20	38	<5	<13
	1800	17	20	17.9	11	21	<5	<13
	1900	15	17	18.2	8	15	<5	<13
	2000	24	29	17.3	12	23	<5	<13
	2100	16	19	18.0	11	21	<5	<13
	2200	15	17	18.9	6	11	<5	<13
	2300	26	30	19.0	6	0	<5	<13
	2400	76	88	20.6	3	6	<5	<13
08/24	0100	124	144	19.9	0	0	<5	<13
	0200	139	161	20.1	0	0	<5	<13
	0300	139	161	20.3	3	6	<5	<13
	0400	138	160	20.3	3	6	<5	<13
	0500	137	160	20.3	1	2	<5	<13
	0600	138	160	20.4	0	0	<5	<13
	0700	242	281	20.0	0	0	<5	<13
	0800	150	174	16.5	20	38	7	19
	0900	50	58	14.4	36	69	6	16
	1000	65	75	16.1	22	42	5	13
	1100	148	172	17.2	19	36	9	24
	1200	149	173	14.8	42	80	10	27
	1300	79	92	13.6	60	115	12	32
	1400	18	21	12.8	66	126	7	19
	1500	19	22	14.7	49	94	6	16
	1700	48	56	17.8	5	10	6	16
	1800	33	38	17.9	5	10	<5	<13
	1900	22	26	18.0	5	10	<5	<13
	2000	38	44	17.8	5	10	<5	<13
	2100	10	12	18.1	5	10	<5	<13
	2200	10	12	18.4	5	10	<5	<13
	2300	19	22	18.6	5	10	<5	<13
	2400	53	61	19.0	5	10	<5	<13
08/25	0100	107	124	19.5	5	10	<5	<13
	0200	146	162	19.6	5	10	<5	<13
	0300	152	176	19.7	5	10	<5	<13
	0400	154	179	19.8	5	10	<5	<13
	0500	160	186	19.8	5	10	<5	<13
	0600	154	179	19.8	5	10	<5	<13
	0700	304	353	17.7	15	29	7	19
	0800	128	148	16.4	34	65	16	43
	0900	139	161	13.0	75	143	21	56
	1000	135	157	14.6	38	73	12	32
	1100	112	130	15.3	28	53	7	19
	1200	64	74	16.7	18	34	6	16
	1300	74	86	14.3	5	10	7	19

TABLE A-22. MARYSVILLE BOILER STACK GASEOUS EMISSION DATA*

Date	Chlorides		Fluorides		NO$_x$		SO$_x$	
	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)
04/26	23.0	15.9	0.5	0.6			130.4	19.8
04/27	13.0	9.0	0.2	0.3			135.1	51.6
04/28	5.8	4.0	0.7	0.9			123.3	47.1
07/17	9.3	6.4	0.3	0.3			64.2	24.5
07/18	130.5	90.0	2.0	2.6			91.1	34.8
07/19	20.1	14.2	0.5	0.7			66.1	25.2
07/19	101.4	70.0	1.1	1.4			50.7	19.4
07/20	73.8	50.9	0.6	0.7	157.3	83.7	41.3	15.8
07/21	136.4	94.1	1.0	1.3	93.3	49.7	45.4	17.3
08/18	31.7	21.9	1.1	1.4			71.7	27.4
08/21	8.8	6.1	0.7	0.9			44.5	17.0
08/24	4.2	2.9	0.9	1.2	156.6	83.3	56.6	20.1
08/24	10.1	7.0	0.8	1.0	195.6	104.1	42.9	16.4
08/24	9.2	6.4	0.9	1.2			62.9	24.0
08/25	5.5	3.8	0.9	1.1	217.4	115.6	45.5	17.4
08/25	10.3	7.1	1.7	1.2	220.3	117.2	62.8	24.0
Average	37.1	25.6	0.9	1.1	173.4	92.3	70.9	27.1
Standard Deviation	$\sigma = 44.7$		$\sigma = 0.5$		$\sigma = 43.9$		$\sigma = 30.9$	

*Using wet chemistry techniques.

TABLE A-23. MARYSVILLE BOILER STACK GASEOUS EMISSION DATA DURING BURNDOWN*

Date	Chlorides		Florides		NO_x		SO_x	
	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)	(mg/m^3)	(ppm)
08/22	0.9	0.6	2.3	2.9				
08/22	1.7	1.2	1.6	2.1			26.2	10.0
08/22	0.1	0.1	0.2	0.3			73.8	28.2
08/23	0.3	0.2	<0.2	<0.2			2.6	1.0
08/23	0.1	0.1			40.4	21.5	17.8	6.8
08/23	2.3	1.6	0.6	0.8			551.8	210.8

*Using wet chemistry techniques on impinger solutions.

TABLE A-24. MARYSVILLE TOTAL HYDROCARBON EMISSIONS

Date	Time	Total hydrocarbons (ppm)	Date	Time	Total hydrocarbons (ppm)
4/24	1400	62.3	7/20	1345	47.0
	1500	69.2		1347	9.0
	1600	24.2		1355	137.0
	1630	10.4		1515	52.0
4/26	1400	5.1	7/21	0926	899.0
	1410	2.0		0927	807.0
	1420	3.7		0928	624.0
	1430	2.7		0942	440.0
	1440	1.6		0947	936.0
	1500	2.9	8/21	1046	34.0
	1520	1.8		1048	134.0
	1540	1.2		1050	104.0
	1600	5.9		1052	81.0
	1630	1.2		1054	31.0
4/28	0800	1.9		1100	10.0
	0900	3.0		1108	6.0
	1000	1.7	8/21*	2320	26.0
7/17	1500	44.0	8/22*	0040	1.0
	1600	94.0		0432	4.0
	1630	10.0		2320	30.0
	1700	24.0	8/24	1135	30.0
7/18	0910	260.0		1138	43.0
			8/25	0722	19.0
				1335	10.0
			Average		121.1

* during burndown period

TABLE A-25. MARYSVILLE STACK GAS HYDROCARBON ANALYSIS

Date	Time	C_1 (ppm)	C_2 (ppm)	C_3 (ppm)	$>C_3$ (ppm)
7-18-78	0948	667	333	17	200
	0958	967	650	33	333
	1000	83	33	47	33
	1005	267	183	33	267
	1008	767	433	33	333
	1012	217	100	133*	
	1050	415	132	166*	
	1100	<16	<16	83*	
	1108	714	515	664*	
	1112	564	365	66	166

* greater than C_2

APPENDIX B

CALCULATIONS

CALCULATION B-1. VOLUME AND WEIGHT REDUCTION OF OCTOBER REFUSE AT NORTH LITTLE ROCK

Data Input

1. As-received weight of refuse burned = 450,000 lb
2. Refuse density = 165 lb/yd^3
3. Average refuse moisture = 22%
4. Residue wet weight = 202,460 lb
5. Residue density (wet basis) = 1,510 lb/yd^3
6. Residue moisture = 32.5%
7. Combustible percent residue (wet basis) = 5.9%
8. Inert percent of residue (wet basis) = 61.7%
9. Small fraction percent of residue = 69.0%
10. Percent (dry basis) of combustibles in residue small fraction = 12.7%
11. As-received percent of inerts in refuse = 24.5%

Calculations

1. Volume of residue (V_r):

$$V_r = 202{,}460 \text{ lb}/1510 \text{ lb/yd}^3 = 134 \text{ yd}^3$$

2. Volume of refuse (V_R):

$$V_R = 450{,}000 \text{ lb}/165 \text{ lb/yd}^3 = 2727 \text{ yd}^3$$

CALCULATION B-1. (continued)

3. Volume reduction of refuse (R_v):

$$R_v = 1 - V_r/V_R = 1 - 134/2727 = 0.95$$

4. Weight reduction of refuse (R_w):

$$\text{Dry basis:}\quad R_w = 1 - \frac{202{,}400\ (1 - .325)}{450{,}000\ (1 - .22)} = 0.61$$

$$\text{Wet basis:}\quad R_w = 1 - \frac{202{,}400}{450{,}000} = 0.55$$

CALCULATION B-2. TOTAL HEATING VALUE OF OCTOBER RESIDUE AT NORTH LITTLE ROCK

SYSTECH Data Calculation

1. Residue wet weight = 202,000 lb
2. Moisture in residue = 32.5% (202,000 lb) = 65,650 lb
3. Residue dry weight = 202,000 lb - 65,650 lb = 136,350 lb
4. Small fraction in residue = 69% (136,350 lb) = 94,082 lb
5. Combustibles in residue = 12.7% (94,082 lb) = 11,948 lb

Commercial Laboratory Data Calculation

1. Small fraction in residue = 94,082 lb
2. Btu/lb of small fraction (average) = 1363 Btu
3. Heating value = 94,082 lb (1363 Btu/lb)

   = 128 MBtu

CALCULATION B-3. NORTH LITTLE ROCK OCTOBER MASS FLOW RATES

1. Data from Field Tests

Average stack flow rate (V_s) = 22,860 ACFM

CO_2 in stack $CO_2(s)$ = 4.4%

CO_2 in boiler $CO_2(B)$ = 9.5%

Average temperature of stack gases = 286° F

Average temperature of boiler gases $T_{(b)}$ = 450° F

Average temperature of ambient air $T_{(a)}$ = 66° F

2. To calculate aspirator (V_A) and combustion (V_B) fans:

$$\% CO_2(A)\ (V_A) + \% CO_2(B)\ (V_B) = \% CO_2(S)\ (V_S)$$

3. To calculate mass flow rate of stack gases:

$$M = \frac{PVM}{R(T + 460)} \quad (\text{lb/min})$$

where

$R = 0.7302 \ \frac{\text{atm. ft}^3}{\text{mole}_{\text{lb}} \ {}^\circ\text{R}}$ gas constant

P = 1 atm.

T = temperature °F

M = molecular weight of gas

$\dot{V} = \frac{\%\ \text{concentration (by volume)}}{100} \times \dot{V}_x$ (ACFM)

$\dot{V}_x$ = total gas flow rate at boiler, aspirator, or stack

CALCULATION B-4. MARYSVILLE MASS BALANCE JULY TEST

1. Refuse Input
   From tables in text 28.28 tons

2. Quench Water Input
   gallons from data sheets
   4387 gal × 8.34 lb/gal = 18.3 tons

3. Natural Gas Input
   $12 \text{ MCF @ } 20 \text{ psig} \times .045 \frac{\text{lb}}{\text{ft}^3} \times \frac{20 + 14.7}{14.7} = .64 \text{ ton}$

4. Air Flow in by Difference 323 tons

5. Residue Out
   From tables in text 1 ton

6. Flue Gas Out
   Heat recovery 369 tons
   Burndown 197 tons

CALCULATION B-5. NORTH LITTLE ROCK ENERGY LOSSES

1. Refuse Input
   From Table 10 in text 2150 MBtu

2. Natural Gas Input

$$10 \text{ MCF} \times \frac{20 \text{ psig} + 14.7}{14.7} \times 1 \frac{\text{MBtu}}{\text{SCF}} = 23.6 \text{ MBtu}$$

3. Electricity Input
   Measured in previous tests,

   40 Btu/lb of refuse fired as received × 450,000 lb = 18 MBtu

4. Flue Gas Losses

   $Q = M C_p (\Delta T) = 832$ MBtu

   M = masses obtained from mass balance

   C_p = specific heat for each component used

5. R/C Losses
   From Calculation B-11. 0.82 MBtu

6. Residue losses
   From Table 12 in test

   1 ton @ 5.9% C = .059 ton of carbon

   14.500 Btu/lb × .059 = 1.71 MBtu

7. Steam output
   From steam recorder integrator

   977,000 lb × 1183 Btu/lb = 1159 MBtu

CALCULATION B-6. MARYSVILLE JULY ENERGY BALANCE

1. Refuse Energy Input

   Wood: 37,401 lb × 7,700 Btu/lb = 287.9 MBtu
   Paper: 14,260 lb × 7,700 Btu/lb = 109.8 MBtu

2. Natural Gas Input

   From field data

$$12 \text{ MCF} \times \frac{14.7 \text{ psia} + 20 \text{ psig}}{14.7} \times 1 \frac{\text{MBtu}}{\text{MCF}} = 28 \text{ MBtu}$$

. Electricity Input

   From computer program

   57 Btu/lb of waste fired as received
   57 Btu/lb × 55,560 lb = 3.2 MBtu

4. Burndown losses

   From Calculation B-12

   R/C losses: 530,057 Btu/hr × 40 hr = 21.2 MBtu
   Stack heat loss: 10.64 MBtu/cycle × 5 cycles = 53.2 MBtu
   74.4 MBtu

5. Residue losses

   From Table 48 in the text

   1 ton @ 2.75% C = .0275 ton of carbon
   14,500 Btu/lb × .0275 = .79 MBtu

6. Flue gas losses

   From computer program of ASME codes 102 MBtu

7. Hot water out

   148 MBtu during test period adjusted to 142 MBtu after calibrating meter

8. Radiation and convection losses

From Calculation B-12

730,000 Btu/hr × 75.38 hr = 55 MBtu

9. Time

From field data

75.38 hr for heat recovery
44.62 hr for burndown

120.00 hr

CALCULATION B-7. NORTH LITTLE ROCK OCTOBER WATER BALANCE

	Moisture	H_2O (lb)
1.	Moisture in refuse	
	From Tables 4 and 5 in the text	
	450,000 lb × .22 percent moisture =	99,000 lb
2.	Moisture in combustion air from aspirator and blower as calculated in Calculation B-3	51,974 lb
3.	Burning of hydrogen	
	Hydrogen in refuse from ultimate analysis Table 8 in the main text	
	$2H_2 + O_2 \rightarrow 4H_2O$ $19,848 + 8 (19,848) \rightarrow$	173,250 lb
4.	Total	324,224 lb
5.	Measured stack flow From field data	328,542 lb

CALCULATION B-8. MARYSVILLE JULY WATER BALANCE

Moisture — H_2O (lb)

1. Moisture in refuse

From Table 21 in text — 4,830

2. Moisture in combustion air

% by wt × airflow moles/min × time = wt

Airflow by difference

H_2O during heat recovery — 3,800
H_2O during burndown — 2,225

3. Water quench spray

Measured from field data — 36,580

4. Moisture from hydrogen combination

$2H_2 + O_2 \rightarrow 4H_2O$

Wood: 7.08% H × 37,401 lb = 2,648
Paper: 6.85% H × 14,260 lb = 977

3,625 lb H

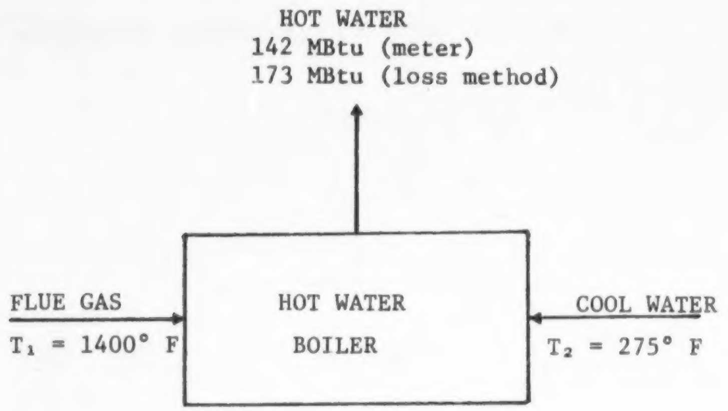
3625 lb + 8 (3625 lb) = 32,624

5. Total — 70,059 lb

6. Measured stack flow

From field data
% H_2O × flow rate (moles/min) × M.W. × time = 73,036 lb

CALCULATION B-9. MARYSVILLE BOILER THERMAL EFFICIENCY FOR JULY TEST


HOT WATER
142 MBtu (meter)
173 MBtu (loss method)
FLUE GAS
T₁ = 1400° F
HOT WATER
BOILER
COOL WATER
T₂ = 275° F

$$\eta = \frac{\text{heat transferred to hot water}}{\text{sensible heat in gases}} = \frac{M_W\ (h_2 - h_1)}{M_g\ C_p\ (T_2 - T_1)}$$

where

$M_W\ (h_2 - h_1)$ = 142 MBtu by Btu meter

= 173 MBtu by loss method balance

Mg (HHV) = 700,560 lb

Mg (NET) = 738,000 lb

C_p = 0.26 Btu/lb ° F

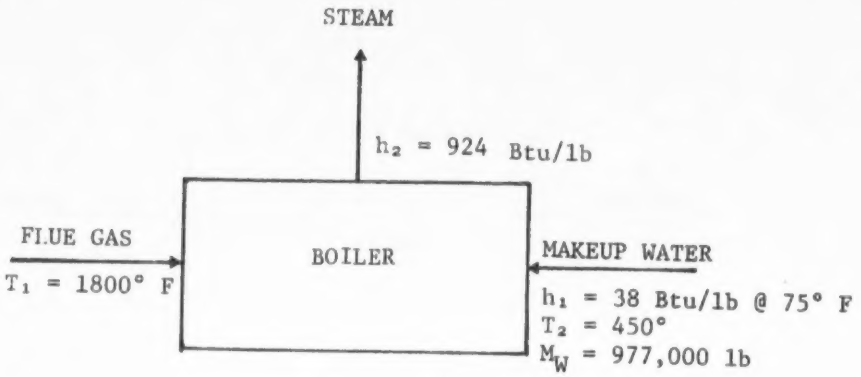
$$\text{HHV } \eta = \frac{142 \text{ MBtu}}{738{,}000 \text{ lb } (0.26 \text{ Btu/lb } ^\circ\text{F}) \ (1400 - 275)^\circ \text{ F}} = 0.66$$

$$\text{HHV } \eta = \frac{173 \text{ MBtu}}{738{,}000 \text{ lb } (0.26 \text{ Btu/lb } ^\circ\text{F}) \ (1400 - 275)^\circ \text{ F}} = 0.80$$

$$\text{Net } \eta = \frac{142 \text{ MBtu}}{700{,}560 \text{ lb } (0.26 \text{ Btu/lb}^\circ \text{ F}) \ (1400 - 275) \ ^\circ \text{ F}} = 0.69$$

$$\text{Net } \eta = \frac{173 \text{ MBtu}}{700{,}560 \text{ lb } (0.26 \text{ Btu/lb}^\circ \text{ F}) \ (1400 - 275) \ ^\circ \text{ F}} = 0.84$$

CALCULATION B-10. NORTH LITTLE ROCK BOILER THERMAL EFFICIENCY FOR OCTOBER TEST


STEAM
h₂ = 924 Btu/lb
FLUE GAS
T₁ = 1800° F
BOILER
MAKEUP WATER
h₁ = 38 Btu/lb @ 75° F
T₂ = 450°
M_W = 977,000 lb

$$\eta = \frac{\text{heat transfered to steam}}{\text{sensible heat in gases}} = \frac{M_W\,(h_2 - h_1)}{Mg\ C_p(T_2 - T_1)}$$

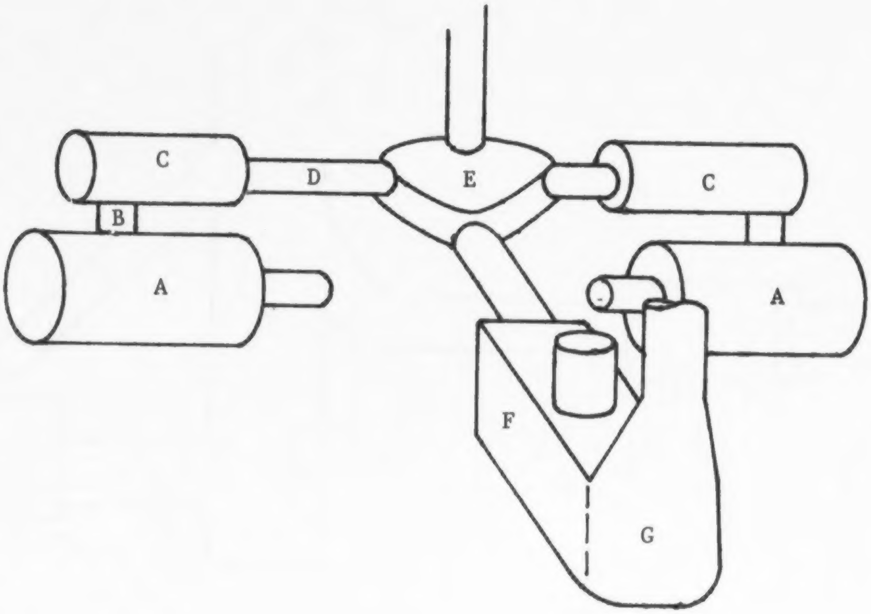
where

C_p = 0.27 Btu/lb ° F

Mg (HHV) = 4,374,514 lb
Mg (NET) = 4,018,299 lb

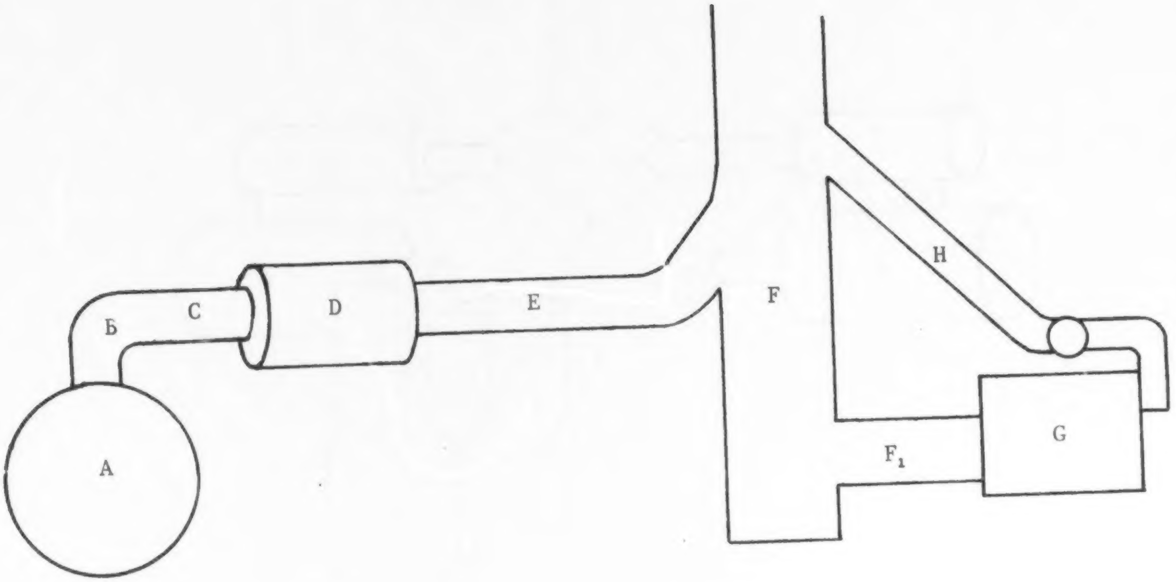
$$\text{HHV } \eta = \frac{977{,}000 \text{ lb } (1174 - 38) \text{ Btu/lb}}{4{,}314{,}514 \text{ lb } (0.270 \text{ Btu/lb } ° \text{ F}) \ (1800 - 450)° \text{ F}} = 0.71$$

$$\text{NET } \eta = \frac{977{,}000 \text{ lb } (1174 - 38) \text{ Btu/lb}}{4{,}018{,}239 \text{ lb } (0.270 \text{ Btu/lb° F}) \ (1800 - 450)° \text{ F}} = 0.76$$



CALCULATION B-11. RADIATION AND CONVECTION LOSSES AT NORTH LITTLE ROCK FACILITY

Object	Description	Q_C (Btu/hr)	Q_R (Btu/hr)
A_3	Primary Combination Chamber	90,757	131,584
A_4	Primary Combination Chamber	94,900	137,442
B_3	Duct	1,316	2,305
B_4	Duct	1,316	2,305
C_3	Secondary Combination Chamber	5,894	10,338
C_4	Secondary Combination Chamber	5,894	10,338
D_3	Duct	28,392	43,273
D_4	Duct	30,737	47,721
E	Plenum	52,814	90,366
F	Boiler	16,953	28,476
G	Aspirator	32,010	51,562
	Total	360,983	555,710



CALCULATION B-12. RADIATION AND CONVECTION LOSSES AT MARYSVILLE FACILITY

Object	Description	Q_C	Q_R
A	Primary Chamber	64,897	95,023
B	Duct, Elbow	4,215	9,608
C	Duct	14,523	22,432
D	Inspirator	14,842	21,700
E	Duct	105,627	177,190
F	Stack	42,847	71,852
F_1	Duct	11,764	19,742
G	Boiler	4,578	8,375
H	Duct	16,320	24,026

CALCULATION B-13. MARYSVILLE BURNDOWN DATA

Temperature/Time	Sample point	Δ temperature	Flue gas data from August test SCFM	Components	
Tamb = 55°F		745	1801@	O_2	18.8
T/0 = 800	A	745	(211°F)	CO_2	1.8
T/.5 = 800				N_2	79.4
		545		H_2O	1.79
T/1.0 = 600		445	2151@		
T/2.0 = 500	B		(485°F)	H_2O	2.93
		425			
T/3.0 = 480		425			
T/4.0 = 480		405			
T/5 = 460		375	2200@	H_2O	7.04
T/6 = 430	C		(459°F)		
		345			
T/7 = 400					

$Q = MCp\Delta T$

CO_2: Cp = .2015

O_2: Cp = .2191

N_2: Cp = .2483

CALCULATION B-13. (continued)

Mass flow at point A

$$V = (1801)(.4719)(60) = 50{,}994\ \ell/\text{min}$$

$$PV = NRT, \qquad P = 1\ \text{atm}$$

$$50{,}994 = N(.08205)(294) = N(24.12)$$

$$N = \frac{V}{(.08205)(294)} = \frac{V}{24.12} = \frac{50{,}994}{24.12} = 2114\ \text{Moles/min}$$

	%		g/mole		m/min				
CO_2:	.018	×	44	×	2114	=	1,674 g/min	=	221 lb/hr
O_2:	.188	×	32	×	2114	=	12,718 g/min	=	1,680 lb/hr
N_2:	.794	×	28	×	2114	=	46,998 g/min	=	6,211 lb/hr
H_2O:	.0179	×	18	×	2114	=	618 g/min	=	90 lb/hr

Mass flow at point B

$$V = (2151)(.4719)(60) = 60{,}903\ \ell/\text{min}$$

$$PV = NRT, \qquad P = 1\ \text{atm}$$

$$N = \frac{V}{24.12} = \frac{60{,}903}{24.12} = 2525\ \text{Moles/min}$$

	%		g/mole		m/min				
CO_2:	.018	×	44	×	2525	=	1,999 g/min	=	264 lb/hr
O_2:	.188	×	32	×	2525	=	15,190 g/min	=	2,007 lb/hr
N_2:	.794	×	28	×	2525	=	56,136 g/min	=	7,418 lb/hr
H_2O:	.0293	×	18	×	2525	=	1,332 g/min	=	175 lb/hr
									9,866 lb/hr

CALCULATION B-13, (continued)

Mass flow at point C

$$V = (2200)\ (.4719)\ (60) = 62{,}290\ \ell/\text{min}$$

$$N = \frac{62{,}290}{24.12} = 2583\ \text{moles/min}$$

	%		g/moles		moles/min		g/min		lb/hr
CO_2:	.018	×	44	×	2583	=	2,046	=	270.362
O_2:	.188	×	32	×	2583	=	15,539	=	2,053.655
N_2:	.794	×	28	×	2583	=	57,425	=	7,589.241
H_2O:	.0704	×	18	×	2583	=	3,273	=	432.578

Heat loss at point A

$$Q = MCp\Delta T$$

							MBtu/hr
CO_2:	221	×	.2015	×	745	=	.033
O_2:	1680	×	.2191	×	745	=	.274
N_2:	6211	×	.2483	×	745	=	1.148
H_2O:	90	×	1170 Btu/lb @ 274° F			=	.105
							1.561

Heat loss at point B

CO_2:	264	×	.2015	×	445	=	.023
O_2:	2007	×	.2191	×	445	=	.195
N_2:	7418	×	.2483	×	445	=	.819
H_2O:	175	×	1204 Btu/lb			=	.211
							1.25

CALCULATION B-13, (continued)

Heat loss at point C

CO_2: 270 × .2015 × 375 = .202

O_2: 2053 × .2191 × 375 = .168

N_2: 7589 × .2483 × 375 = .706

H_2O: 432 × 1194 Btu/lb = .516

1.412

Total heat loss from stack/period

$Q = MCp\Delta T$

A × 1 hr + B × 5 hr + C × 2 hr = 1.561 + 6.255 + 2.824

= 10.641 MBtu

Heat loss by R/C see Calculation B-12/period

			Total/hr
P.C	C = 69,112 Btu/hr	R = 104,631 Btu/hr	= 173,743 Btu
A.B	C = 134,992 Btu/hr	R = 221,322 Btu/hr	= 356,314
			530,057 Btu

Total/period = 4.24 MBtu = 8 hr × 530,057 Btu

Total/week = 14.88 MBtu/period × 5 periods = 74.4 MBtu

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